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ELECTRICITY

AND ITS DISCOVERERS

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A POPULAR EXPOSITION

OF

ELECTRICITY

1.

WITH SKETCHES OF SOME OF ITS DISCOVERERS.

BY

REV. MARTIN S. BRENNAN, A. M.,

RECTOR OF THE CHURCH OF ST. THOMAS OF AQUIN, ST. LOUIS, MO.

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PREFACE.

THE recent extraordinary progress of electricity, its stimulus to commerce, and its mysterious possibilities, make it, *par excellence*, the science of sciences of our day. All should be familiar with its essential principles at least.

Many learned and excellent treatises have been devoted to the subject, but so illustrated with complex and intricate mechanical diagrams as to frighten away the timid and uninitiated.

My sole aim in this little book is simplicity. The mechanical part of the science is continually changing; new patents are being daily issued, so that a thorough and full description of the multiplex machinery, except for a professional, would be time wasted. I have, therefore, devoted my

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care almost entirely to the explanation of principles, to the exclusion of mechanics.

I consider, moreover, that complicated diagrams, by drawing away the mind from the subject-matter in hand, confuse rather than simplify.

I have aimed throughout at manifesting the identity of all the forms of electricity, and have accordingly so arranged the matter that each succeeding form naturally flows from its predecessor.

I have also given short sketches of the men who have added most to the science by their great discoveries, and placed the man as closely as possible to his work.

Women should be especially interested in electricity. It is woman's science. A woman was the discoverer of its dynamic branch. The wife of Galvani, the bright daughter of the eminent Galeazzi, is the initial link in the golden chain of illustrious discoverers who have given to us the modern science of electro-dymanics.

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ELECTRICITY
AND ITS DISCOVERERS.

CHAPTER I.

MAGNETISM.

ELECTRICITY, under the form of magnetism, seems to have been both recognized and utilized by mankind from all antiquity. There is a dim tradition that the magnetic chariot, *tchi nan*, was used in a rude form by the Chinese as far back as the reign of the Emperor Hoangti, twenty-six hundred years before our era. A wagon of this kind, to guide the traveler over the great wastes of Asia, was certainly in use eleven hundred years before Christianity.

In this apparatus a freely floating needle moved the arm and hand of a small figure, which pointed toward the south. This wagon was in use in Asia down to the fifteenth century.

The magnetic needle was unknown in Europe prior to the eleventh or twelfth century. William Gilbert, of Colchester, born in 1540, was the first to write a regular treatise on magnetism and reduce the subject to a scientific basis. According to his testimony, Marco Polo was the first European who applied the magnetic needle to the purposes of navigation. This he did in returning to Europe from the East Indies, in the year 1260. According to other and more probable testimony, however, the magnetic needle was known in European seas some seventy years previously.

Magnetism is derived from Magnesia, a town of Lydia, in Asia. An ore of iron, called lodestone, has the property of attracting to itself small particles of iron, cobalt, and nickel; and as this ore was found in great abundance in Magnesia, it was called by Pliny *magnes*, and hence magnet.

Lodestone is the magnetic oxide of iron, Fe_3O_4, and is a union of the protoxide and sesquioxide of iron. The scales thrown off under the smith's hammer are this oxide.

Lodestone, mounted in a soft-iron frame, constituted the original magnet.

Magnets are natural, artificial, and permanent. The magnetic ore of iron is the natural magnet.

Steel or hardened iron, when brought into contact with a magnet, becomes magnetized, and is called an artificial magnet. Soft iron is magnetic only when in contact with a magnet, and, when parted from the magnet, at once loses the magnetic property.

Hardened steel, once magnetized, never loses its magnetism, and hence is called a permanent magnet.

When a small magnetic steel bar is freely suspended on a pivot, it will so arrange itself that one end will point toward the north, and the other end, by consequence, toward the south; and, however the bar be moved thereafter, it will invariably, the disturbing force being withdrawn, restore itself to this position, the same end as before pointing north, and the same south. This is the most obvious property of a magnet, and is called polarity.

The needle of the compass is simply a magnetized piece of steel, balanced upon a pivot, and placed in a box having a circular card, divided into thirty-two equal parts. The end pointing north is called the north pole of the magnet, and the end pointing south, the south pole. The unlike poles of two magnets attract each other, while similar poles repel; that is, a north pole will attract a south pole and repel a north pole, and a south pole will repel a south pole and attract a north pole.

When a piece of soft iron is brought into contact with a permanent magnet, the soft iron will itself become magnetic, and, while in connection with the magnet, will attract other smaller pieces of metal. This process is called induction, for the magnet induces its own magnetic property in the soft iron. The soft iron, however, loses its magnetism immediately on the withdrawal of the magnet. A magnet will induce magnetism in soft-iron filings in its immediate vicinity, although not in actual contact. Magnets, natural or artificial, can induce by touch permanent magnetism in a rod of steel or hardened iron.

When one of the poles of a magnet touches the end of a soft-iron rod, that portion of the rod in contact with the pole will assume the opposite magnetism to that of the pole; the positive pole inducing negative magnetism, and the negative pole positive magnetism. The magnetism of the other extremity of the rod will be similar to that of the pole.

If the pole of a magnet touches the center of an iron bar, the magnetic fluid of the center will be opposite, and that of both ends of the bar will be similar to that of the pole. If either pole be brought in contact with the center of a circular plate of iron, the center will have opposite and the rim similar magnetism to that of the pole.

If a bar-magnet be broken in the center, the pieces, instead of having all positive or all negative, will each have both positive and negative polarity, so that neither can ever be entirely eliminated, or parted from the other.

The generally accepted theory of magnetism is that, in any body capable of being magnetized, such, for instance, as a bar of iron, there exist two fluids, one called the boreal, northern, or positive; and the other the austral, southern, or negative. These fluids, in an ordinary piece of soft iron, are combined together, and so are in the latent state. When the iron becomes magnetized, these fluids are set free, one rushing to one and the other to the other extremity of the bar. Every atom or molecule of iron contains both these fluids, and can never part with them; the only change occurring is the decomposition of the fluids into their separate elements. In a permanent magnet the fluids are disunited in each and every single molecule, the positive fluid ranging itself on one side of the molecule and the negative on the other. The positive of each atom throughout the bar neutralizes or disguises the negative of its neighboring atom, excepting the positive and negative of the atoms at the extreme ends. Thus, the fluids of one side of the two extreme atoms are free, the positive fluid constituting the positive pole, and the negative fluid the negative pole of the magnet. This explains the reason why the central portion of a magnet has no magnetic properties, the positive fluid of each particle disguising the negative fluid of its neighbor. Hence, also, a magnet in the form of a ring gives no evidence of free magnetism, but, being broken, the fragments will be found to be highly magnetic.

The process of induction in soft iron is explained in a similar manner. When a rod of soft iron is approached toward the negative pole of a magnet, the fluids of the atom in immediate proximity to this pole are separated, the positive being forced to the side nearest the magnet, and the negative to the other side. This last negative holds the positive of the second atom, sending its negative to the opposite side, and so on, until the last atom is reached, and its positive is disguised by the preceding atom's negative and its own negative is set free. The magnet being removed, the fluids are recombined, and the rod loses its polarity.

Another theory, more complex, much in vogue, however, and very ingenious, is Ampère's. According to Ampère, currents of electricity are incessantly running around every particular molecule of a magnet. The resultant of these small currents produces a great current circling the magnetic bar. The difference between a magnet and an ordinary rod of iron is, that in the latter the electricity is latent, and in the former in an active state of motion.

The harder and more dense the steel, the more difficult it is to be magnetized, but the more permanent the magnet. It would appear that the closeness of the molecules offers a mechanical impediment to the free movement of the imponderable magnetic fluids.

Hitherto only iron, cobalt, and nickel have been mentioned as sensitive to magnetic influence, but Faraday by his experiments discovered many other substances susceptible of polarity. Manganese, chromium, cerium, titanium, palladium, platinum, osmium, and arsenic, with their salts and even solutions, are thus susceptible.

Dr. Faraday by his brilliant researches, besides adding greatly to the development of electric science in general, did more than any other man to demonstrate the identity of magnetism and electricity.

The process by which a piece of steel is converted into a magnet is technically called a "*touch*." There are many kinds of touches. The single touch is the simplest mode of generating magnetism in a steel rod. This is accomplished by running one pole of a magnet several times over the bar to be magnetized, always, however, in the same direction. The end of the bar last touched by the positive pole of the magnet will become a negative pole.

Magnets are commonly shaped like the letter U, and have received the name of horseshoe magnets. Several of these magnets are sometimes joined together, and thus form a very powerful one, or rather a battery of magnets. Magnetism exists entirely on the surface, so that a magnetic hollow cyclinder will be equally powerful as if it were solid. A number of small magnets connected together have more power than the same weight of metal in a single magnet, because they present more surface. Rust, grinding, filing, weaken the power of a magnet, showing magnetism to have more to do with the surface than the interior.

When magnets are left to themselves, they constantly, though very slowly, lose their magnetism. To prevent this loss, a piece of soft iron, called the armature, is placed across the poles. The armature, becoming magnetic, seems to react upon the magnet, and thus not only to conserve its magnetism, but really to increase its intensity. Small weights suspended from the armature, and occasionally increased, will increase the strength of the magnet to a certain limit. Thus, a one-pound magnet can be made to lift a weight of twenty-eight pounds.

The attractive force of a magnet is diminished by raising its temperature. A magnet heated slightly loses a portion of its power, but regains it again upon cooling. When heated to redness, it loses its polarity completely, and does not recover it upon cooling. On the contrary, a decrease of temperature increases the magnetic force.

Coulomb, with a torsion-balance, has found that the force of magnetic attraction is inversely as the square of the distance, which is the law governing the intensities of heat, light, and gravitation.

A bar of soft iron, when acted upon by a magnet, is equally attracted by both poles, and when such a bar is freely suspended over the poles of a horseshoe magnet, it will so arrange itself as to be in the line of the magnetic force—that is, in the direction of a line connecting the poles.

Dr. Faraday found that certain bodies, when approached by a magnet, were repelled by both poles; and bars of such substances, when freely suspended over the poles of a magnet, arranged themselves at right angles to the direction of the magnetic force. All bodies attracted by a magnet, however feebly, are called magnetic, and those repelled diamagnetic.

The principal diamagnetic substances, in the order of susceptibility, are bismuth, antimony, zinc, tin, cadmium, mercury, silver, copper.

Animal flesh has been found to be diamagnetic, and a man suspended freely in a horizontal position over the poles of a powerful magnet would be repelled by both poles, until he pointed due east and west, the direction of the poles of the magnet being north and south.

One of the most splendid discoveries of Faraday was that the oxygen of the air is magnetic. This property of oxygen must, consequently, be an element in the explanation of the origin of electric storms and of the aurora borealis. The earth itself is considered a great magnet. Gauss estimates its magnetic force to be as great as if every cubic yard of it contained six one-pound magnets.

According to Ampère the magnetism of the earth is occasioned by electric currents constantly circling it from east to west in spiral lines. These currents are caused by the sun's rays. These spirals induce in the earth a magnetic axis at right angles to themselves, and whose poles nearly coincide with the earth's geographical poles.

Both natural and artificial magnets owe their polarity to induction from the earth. Tools in workshops, placed vertically, become magnetized. A bar of iron, placed in the magnetic meridian, and inclined at an angle corresponding to the dip of the needle for the locality, will become magnetic. Sunlight has a magnetic effect on steel; and needles, placed in glass bottles of a violet or blue color, will become magnets.

Great advances have been made within a very short period in this beautiful science of magnetism, and yet we have but touched the shores of this enchanting wonderland.

CHAPTER II.

THE MARINER'S COMPASS.

THE present mariner's compass is a delicate piece of mechanism. It consists of a long, flat lozenge-shaped magnetized needle, balanced horizontally on a very fine point of some hard substance. Everything possible is done to eliminate friction. The center of gravity of the needle is pierced, and a piece of agate inserted to rest on the point of a steel pin. Beneath the needle and attached to it, so that they move together, is a circular card divided into thirty-two parts, called points. The extremities of the needle point to two divisions of the card diametrically opposite, which are marked N. and S., and correspond to the north and south poles of the needle. The extremities of the diameter running across the card at right angles to the needle are marked E. and W.

The whole circle of 360° is divided into thirty-two points, so that each point consists of 11° 15′. Between the N. and the E., for instance, there are eight points, marked respectively N. by E., N. N. E., N. E. by N., N. E., N. E. by E., E. N. E., E. by N., and E.

The other quadrants are similarly divided. To prevent the compass from being thrown out of a horizontal position by the rolling of the ship, it is attached to a pair of circular brass hoops or gimbals. The outer hoop is firmly fixed to a stationary object, and the inner one is attached to the outer by two pivots at the extremities of a diameter in such a way as to allow it free motion within the outer hoop. The compass-box is attached to the inner hoop by two other pivots at the extremities of a diameter at right angles to the first diameter. In this way the compass may move freely in two directions at right angles to one another, and thus its horizontal position is secured under any and all circumstances.

In the box containing the compass is a black line, called the lubber-line, in the absolute direction of a vertical plane cutting the ship from stem to stern. The helmsman must keep the division of the card which shows his course in contact with the lubber-line.

The compass first used in the Mediterranean was simplicity itself, being merely a piece of lodestone attached to a cork floating in a vessel of water.

It has been found by astronomical observation that the needle does not strictly point due north and due south, but varies sometimes to the east, sometimes to the west, of true geographical north and south. The stars are fixed, and never vary in their relative positions. The variation or declination of the needle for any place or time is found by comparing a star's bearing, as indicated by the needle, and its bearing, as shown by astronomical calculation. Columbus was among the first to notice the variation of the needle. He certainly was the first to perceive that there was a line of no variation. There are places upon the earth's surface where the direction of the needle coincides exactly with the geographic meridian, and these places, connected together by an imaginary and very irregular curve, form the so-called lines of no variation. It is generally admitted that there are two lines of this character, called the east and west line. The course of the west line may be traced from the sixtieth parallel of latitude to the west of Hudson's Bay, thence in a southern direction through the American lakes, to the West Indies, and the extreme eastern point of South America.

The eastern, beginning in the White Sea, runs south in a semicircle until it reaches the seventy-first parallel; it thence runs along the Sea of Japan, whence it takes a westward course across China and Hindostan to Bombay; it then turns east, touches Australia, and goes south. Even these lines are not constant, but move from time to time.

A great deal of care and time have been expended by navigators on this matter of the needle's variation. Their observations have, in a great measure, been systematized, so that they have made elaborate charts and tables of the vagaries of this priceless but too sensitive guide. In the year 1840 General Sabine employed as many as fourteen hundred and eighty observations, to accurately determine the line of no variation in the Atlantic Ocean. It may be remarked, however, that for the ordinary purposes of navigation the needle points toward the north with sufficient accuracy, and the variations may in general be disregarded. When, indeed, there is question of something requiring great delicacy and precision, the proper corrections must be applied.

The magnetic needle has a small daily and even hourly variation. Its north pole declines slightly to the west from sunrise to an hour past noon, then retrogrades toward the east until eight in the evening, and remains stationary during the night. It has, moreover, an annual movement, and a different movement in winter from that in summer. These daily and yearly fluctuations of the needle depend, in all probability, upon the differences of temperature caused by the apparent course of the sun.

The magnetic needle is also more or less disturbed by meteoric showers, electric storms, the aurora borealis, the lightning's flash, and the volcano's throe.

If the magnetic needle be so supported at its center of gravity that, instead of being free to move in a horizontal plane, it is left free to move in a vertical plane, the needle will be found to incline more or less from a horizontal position according to the location on the earth's surface. When north of the equator, the north pole of the needle will incline downward; and, when south, the south pole will incline or dip. A magnetized needle of this kind is called a dipping needle. It is furnished with a graduated scale, circular in form, marking all the degrees of an arc, and situated in a vertical plane just beside the needle. In the construction of the dipping-needle, as in that of the compass-needle, everything is done to reach the minimum of friction. Two tiny steel cylinders are run out from the needle on each side of its center of gravity, and these rest on knife-edges made of agate. The frame supporting the needle is mounted on a tripod having adjusting screws, in order to maintain a perfect level.

The nearer this needle is brought to the magnetic equator, the nearer its approach to a horizontal position, and consequently the less the dip or inclination. The farther it is moved from the magnetic equator in the direction of the magnetic pole, the greater the dip. The magnetic equator is where the needle assumes a perfectly horizontal position, being equally influenced by both poles. The magnetic equator does not correspond exactly with the geographic equator, but makes with it an angle of twelve or thirteen degrees.

The geographic equator of the earth is a perfect curve, or great circle; but the magnetic equator is an irregular double curve, to which the name of aclinic line has been given. The magnetic equator intersects the geographic equator in several places: one point of intersection is in the Island of St. Thomas, and another in the Pacific Ocean, about 142° longitude east from Greenwich. This aclinic line is, however, constantly changing its position.

The magnetic poles of the earth do not coincide with the geographic poles. When the dipping-needle is held directly over the magnetic north pole of the globe, the needle will take a perfectly vertical position, the north pole of the needle pointing downward. If we could place the needle over the south magnetic pole, the needle would assume a perpendicular attitude, the south pole pointing downward.

Sir James Ross, in 1831, trying to find a north-west passage around the American Continent, when in latitude 70° 5′ 17″, near Hudson's Bay, saw the needle take a vertical position. The south magnetic pole has not been located.

When the needle of the compass is placed in the immediate neighborhood of one of the magnetic poles of the earth, it loses its power altogether, and points indifferently in all directions. If a magnetized needle be placed on a cork floating in a pool of water, after a short time the poles of the needle will so arrange themselves as to point permanently north and south, but the cork will not be drawn toward either the north or south shore. From this it is concluded that the influence the earth exercises upon the needle is not attractive, but merely directive.

The intensity of the earth's action upon the magnetic needle varies in different places. The nearer the needle is approached to the magnetic poles, the more sensitive it grows, and the more striking and vivid its movements. As we draw near to the equator, the effect is seen to become more and more feeble.

The intensity of the earth's magnetism is found to be greater in colder than in warmer climes. This intensity is also noticed to be greater in the western and northern than in the eastern and southern hemispheres. The earth's magnetism displays itself with a greater intensity at the following places, in the order in which they are named: St. Petersburg, London, Berlin, Paris, Vienna, Madrid, Rome.

CHAPTER III.

MICHAEL FARADAY.

Michael Faraday, most probably the greatest experimental physicist that ever lived, was the son of very poor parents, his father being a journeyman blacksmith. Michael was born at Newington Butts, near London, on the 22d of September, 1791; and, ten years later, necessity forced his family to seek public relief during a period of great distress in London.

In his thirteenth year he went as newspaper-boy to Mr. George Riebau, a bookseller on Blandford Street; and in his own simple way he tells the hardships of this task: "It was his duty, when he first went, to carry round the papers that were lent out by his master. Often on a Sunday morning he got up very early and took them round, and then he had to call for them again; and frequently, when he was told the paper was not done with, 'You must call again,' he would beg to be allowed to have it, for his next place might be a mile off, and then he would have to return back over the ground again, losing much time, and being very unhappy if he was unable to get home to make himself neat, and to go with his parents to their place of worship." A year later he became an apprentice to Mr. Riebau, and continued in his establishment for eight years. Having an extraordinary taste for reading scientific works, he spent every leisure moment in this pursuit. He was especially fascinated with an article on "Electricity" that he found in an old encyclopædia he was employed to bind, and even constructed an electrical machine consisting principally of an old bottle, and tried to verify for himself by experiment the facts referred to in the article.

While a journeyman book-binder, he had the good fortune to attend some public lectures by Sir Humphry Davy, then in the zenith of his fame. Burning with an ardent love of knowledge, and encouraged by a friend, he had the resolution to apply to Davy for employment. Sir Humphry at first tried to dissuade him from his object of following science as a profession, warning him that Science was a harsh mistress, and, in a pecuniary point of view, but poorly rewarding those who devoted themselves to her service. But nothing could withstand his thorough earnestness, and Davy engaged him as chemical assistant to the Royal Institution of Great Britain. This was the turning-point in his career, and thenceforth his life, with a lover's fervor, was dedicated to the service of science. For fifty-two years, with unexampled patience and a hero's courage, he watched and worked in Nature's inner sanctuary; and for forty of these years he kept the name of England in the first rank of science.

In the latter part of 1813 he accompanied Davy as his amanuensis to the Continent. This journey occupied a year and a half, and brought him into contact with the most noted men of science of that time. Faraday was always remarkable for his method, and so made notes of the famous places he visited, and of the great scientific experiments he witnessed. These notes show the goodness and manliness of his heart, and the early perspicacity of his judgment. On his return to the Royal Institution the rapid progress he made in self-education was marvelous. His work for the next five years in the laboratory and lecture-room was so brilliant as to place him by the side of the first chemists of the day. During this period, also, his life had been one of uninterrupted happiness. But human life is a current that must inevitably flow through rough and broken passages. In his thirtieth year he was unjustly accused of dishonesty, in claiming for himself a discovery of the great Dr. Wollaston in magnetism. This persecution, as undeserved as it was venomous, instead of injuring him, rather served to bring into a brighter light his truth and integrity. Another source of great annoyance to him at the same time was the opposition given by Sir Humphry Davy, through a motive of petty jealousy, to his election as Fellow of the Royal Society. His conspicuous ability, however, triumphed over all obstacles, and on January 8, 1824, he was all but unanimously elected. Faraday tells us that he sought and paid for this title, but it was the only one he ever afterward solicited.

The first mark of honor paid to Faraday's scientific labors was in his thirty-second year, and came from the Cambridge Philosophical Society. The same year he was elected corresponding member of the French Academy of Sciences, and of the Accademia dei Georgofili of Florence. During his lifetime Faraday received ninety-five honorary titles and marks of merit from learned bodies throughout the world, all coming voluntarily and unsolicited. In his thirty-fourth year he was appointed Director of the Laboratory of the Royal Society.

Faraday always had one of the kindliest natures. When in the height of his fame, one of his nieces says of him: "In times of grief or distress his sympathy was always quick, and no scientific occupation ever prevented him from sharing personally in all our sorrows, and comforting us in every way in his power. Time, thoughts, purse, everything was freely given to those who had need of them."

On October 17, 1831, being in his fortieth year, Faraday made the great discovery of his life, and one that will make his name famous for all time to come. He discovered magneto-electricity. It was the reward of seven years of unceasing labor and unwavering scientific faith. In 1824 he had reasoned himself into the belief that this discovery was possible. Professor Oersted, of Copenhagen, about twelve years previously, discovered by accident electro-magnetism, or, that a current of electricity, passing through a wire coiled around a piece of soft iron, will magnetize the iron. Faraday, not by accident, but as the consequence of a clear idea, discovered magneto-electricity, or that a magnet will induce an electric current in a coil of wire. The instant the magnet is inserted in the coil, it induces a current in one direction, and when it is withdrawn it induces a current in the opposite direction. These currents are but momentary; when the magnet rests in the coil, no electricity is perceptible.

These electric discoveries of Oersted and Faraday have a parallel in the history of astronomy. William Herschel, in sweeping the heavens with his telescope, fell by accident upon the planet Uranus, thinking it at first a comet. Urbain Le Verrier, from disturbances recognized in the motions of the known planets, computed the exact place and size of Neptune. As the telegraph is the offspring of electro-magnetism, so the electric light is the product of magneto-electricity. There is the highest scientific authority for saying that this discovery of Faraday is the greatest experimental result ever obtained by an investigator.

His skill as an experimenter was so delicate and ingenious, and his illustrations as a lecturer on physics so lucid, that in these particulars Faraday was never excelled. He left no form of electricity untouched in his endeavors to identify them all.

Although Faraday did valuable service for every branch of physics, his three great discoveries, magneto-electricity, voltaic induction, and definite electro-chemical decomposition, were in electricity. The record of his labors in electricity is contained in his "Experimental Researches," preserved in the "Philosophical Transactions" of the Royal Society.

It is, indeed, a marvel how one man could have accomplished the work reported in these papers. Faraday never had but a very small salary, and for the prosecution of his experiments he had to depend entirely on this salary, so that he says of himself and his assistant, "We were living on the parings of our own skin."

His researches in electricity occupied him twenty-six years. In 1855 Professor Reiss, of Berlin, at that time the greatest statical electrician in Europe, says of these "Researches": "What a wonderful work these researches are in every respect! Incomparable for exhibiting the greatest progress for which science ever was indebted to the genius of a single philosopher, highly instructive by indicating the means whereby the great results were found. If Newton, not quite without reason, has been compared to a man who ascends to the top of a building by the help of a ladder, and cuts away most of the steps after he has done with them, it must be said that Faraday has left to the follower, with scrupulous fidelity, the ladder in the same state as he has made use of it."

His biographer, Dr. Bence Jones, tells us that Faraday's first great characteristic as a philosopher was the trust which he put in facts; and his second was his imagination, which sometimes rose to divination or scientific second-sight. The beauty and nobleness of his character as a man were formed principally of these three great qualities—truthfulness, kindness, and energy.

CHAPTER IV.

STATICAL OR COMMON ELECTRICITY.

THE word itself, electricity, is derived from the Greek of amber, *electron;* because it was while rubbing amber that the property was first perceived. For the first mention of this great natural agent we must go back to the writings of Thales of Miletus, in Asia Minor, one of the seven wise men of Greece, who flourished about 600 years B. C. This philosopher relates the fact that, when amber is rubbed with a silken cloth, it will attract light bodies.

Gilbert of Colchester (1600 A. D.), Otto von Guericke (1672), Hawksbee (1709), and Wehler (1729), bring electricity down to Franklin, Gray, and Du Fay, who between 1730 and 1760 may be said to have systematized the science.

Common electricity, also called statical, is generated by friction. When a tube of glass is briskly rubbed for the space of a few seconds with a dry woolen cloth, the tube will become excited, and, if approached toward small pieces of paper or cork lying on a table, will first attract them, causing them to leap toward it, and then repel them, sending them flying back to the table. Once they touch the table, the tube will again attract them, and again repel them, and so on, while the tube continues excited.

Pieces of amber, sticks of sulphur or resin, when rubbed with dry flannel, will act similarly. If, however, a small ball of pith of elder be suspended by a long silk thread from a convenient support, and an excited glass tube be approached toward it, the tube will at first attract and then repel it, and will continue thereafter to repel it until it touches some substance in connection with the earth, and is thus deprived of this new property imparted to it by the excited tube. And if this pith-ball, thus repelled by the excited glass tube, and while still being so repelled, be approached by a piece of sealing-wax or other resinous substance, also excited by being rubbed with dry flannel or silk, the ball will be instantly attracted by the sealing-wax or resin, held for a short space, and then repelled. If a pith-ball be suspended freely by a silk thread between excited glass and resin, it will oscillate between them like a pendulum, being alternately attracted and repelled by each. Two pith-balls suspended freely by silk threads and hanging close together, when similarly excited by a glass rod, will repel each other. They will also repel each other if similarly excited by a piece of sealing-wax, but if one be excited by rubbed glass, and the other by rubbed sealing-wax, they will attract each other. From these simple experiments it is inferred that there are two kinds of electric excitement, the one of glass, called vitreous or positive, and the one of resin, called resinous or negative. And from these same simple phenomena the great law of electricity has been deduced—that electricities of the same name repel, and those of different names attract each other.

When glass is rubbed with a woolen cloth, the electricity of the glass is positive, and that of the cloth is negative; but when glass is rubbed with cat's fur, the fur is positive, and the glass negative. Sealing-wax becomes positive when submitted to the friction of metallic bodies, and negative when rubbed with most other substances. Thus bodies, by being rubbed with different materials, may pass from the vitreous or positive to the resinous or negative class. To know the nature of the electricity of any rubbed substance, we must know with what it is rubbed. In the following enumeration, each substance, when rubbed by any one preceding it, is negatively electrified; by any one succeeding it, positively: Back of a cat, smooth glass, woolen cloth, feathers, wool, paper, silk, lac, rough glass, sulphur.

A pith-ball, suspended by a silk thread, and excited by rubbed glass or resin, will retain its electricity for a long time, if only surrounded by dry air; but if touched by the hand or a metal rod, it parts instantly with its electricity, while glass, resin, or silk will scarcely remove it at all. Some bodies, therefore, conduct electricity very well, and some others not so well; although all bodies conduct it in some degree. So bodies are said to be good or bad conductors. If the electrified pith-ball be surrounded by damp air, or air containing vapor, instead of dry air, it will lose its electricity quite rapidly. Dry air is a bad conductor, but water is an excellent conductor, and so the vapor of water, when mixed with the air, adds to its conducting power. The following substances are the best conductors, and in the order named: The metals, charcoal, plumbago, pure water, moist snow, steam and smoke, vegetables, and animals. Among bad or non-conductors are resins, amber, sulphur, wax, fat, glass, precious stones, silk, wool, hair, feathers, cotton, paper, dry air, baked wood, and India-rubber. These latter bodies are also called insulators, for they insulate or confine electricity.

An instrument by which the presence of electricity is detected is called an electroscope. There are many different forms of the instrument, but one of the most delicate is the gold-leaf electroscope. This simple apparatus consists of a glass jar having a short brass rod running down through its wooden stopper. From the end of the rod within the jar are suspended two gold leaves, hanging side by side. As soon as any electrified body is touched to the brass rod, it conducts the electricity to the gold leaves, which, being thus similarly electrified, mutually repel each other.

Electrometers are instruments employed to measure the quantity of electricity, and among the most ingenious is Coulomb's torsion-balance. The outer part of this electrometer consists of a glass cage having a long, slender glass neck. Down through this neck, and reaching to about the middle of the cage, runs a light film of spun glass, having attached to it a light beam of gum-lac, ending in a gilt pith-ball. Almost in connection with this pith-ball is another gilt pith-ball, the terminus of a brass rod coming down from the top of the cage. This latter ball is called the carrier-ball. The upper end of the glass thread terminates in a key furnished with an index moving around a circle graduated into 360°. When an excited body touches the rod in connection with the carrier-ball, this ball becomes electrified, and imparts some of its electricity to the other pith-ball. The two balls are thus similarly electrified, and the carrier-ball, being stationary, repels the other ball. The key at the top is turned until, by twisting the glass film, the two balls are again brought together. The number of degrees through which the key has to be turned to overcome the repulsion is a measure of the torsion, and so is an approximate measure of the quantity of electricity. Coulomb found that two bodies, differently electrified, attract each other with a force inversely as the squares of their distances; and two bodies, similarly electrified, repel each other with a force varying inversely as the squares of their distances.

A cheap and simple way of generating electricity is by the electrophorus. It consists of a shallow, circular tray of tin, about a foot in diameter and an inch deep. Melted sealing-wax, or a mixture of two parts of shell-lac and one of Venice turpentine, or, indeed, any resinous preparation, is poured into this tray until it is about half filled, let gradually cool, and made as smooth as possible. A disk of brass, a few inches less in diameter than the tray, and having a glass handle, is provided, to be placed over the tray. The resinous cake is briskly rubbed with dry flannel, and is thereby negatively electrified. The brass disk is then placed on the tray, whose negative electricity attracts and holds the positive electricity of the brass disk, thus setting its negative electricity free, and, if the disk be touched by the hand, the negative electricity will be carried to the earth, leaving the disk positively electrified. If, then, the brass disk be raised by the glass handle, and a conductor approached toward the disk, it will emit a positive electric spark. This process may be repeated a great number of times, as the negative electricity of the resin is not conducted away, but merely acts by induction on the brass disk. In the best form of electrophorus the disk, when in place, is connected with the outside of the tray by means of a tiny brass rod. This avoids the trouble of touching the disk with the finger to carry off the free negative fluid.

When large quantities of electricity are sought, an electric machine must be employed. Probably the best form of machine now used is the plate machine. This consists of a large circular plate of glass supported on an axis between two wooden uprights, and turned by a winch. Attached to the uprights are two pairs of cushions pressing tightly against the glass plate. These cushions are connected with the earth by means of small brass chains. The prime conductor is a hollow arm of brass, forming three sides of a rectangle, and insulated on glass legs. The prime conductor connects with the glass plates by means of a number of brass points approaching to within about one eighth of an inch of the plate. An amalgam is applied to the part of the cushions in connection with the surface of the glass plate. Two parts of zinc and one of tin, melted together, and added to six parts of mercury, previously heated in a crucible, make the best amalgam for the electric machine. The mixture, being stirred until cold, is readily reduced to a fine powder, which requires merely to be formed into a paste with lard to be ready for use. When about to be used, the electric machine should be placed in a dry, warm room, the plate rubbed well with a woolen cloth, and a little fresh amalgam applied to the cushions. By the friction of the plate against the cushions the electricity of the cushions is decomposed, the negative being carried off by the chains to the earth; the positive holds the negative of the glass, setting its positive free, and this free positive draws the negative of the prime conductor, setting its positive free. Thus the prime conductor is positively electrified by giving up its negative electricity to the glass plate. To work the machine to advantage, one thing is imperative, which is ordinarily much overlooked, and it is, that the cushions must be connected with the earth by means of a good conductor. If possible, this connection should be made with the lead pipes supplying the house with water.

For purposes of experiment, when it is desirable to store a large quantity of electricity to be carried from place to place, we must have recourse to the Leyden-jar. This consists of an ordinary glass jar coated on the inside and on the outside with tin-foil to within a few inches of the top. Fitted to the mouth of the jar is a wooden stopper, through which a long brass rod is passed, terminating on the outside in a large brass knob. The lower end of the rod must be connected by a chain or other good conductor with the inside coating of the jar. When the knob is touched to the prime conductor, the inside coating, being in immediate connection with it, becomes positively electrified. The positive electricity of the inner coating acts by induction through the glass on the outside coating, decomposing its electricity, attracting and holding fast the negative, and setting free the positive, which escapes by means of the hands to the earth. The jar must be held in the hands or otherwise connected by a good conductor to the earth, that its positive electricity may escape, or the jar will not be charged. There is then free negative electricity on the tin-foil of the outside, and free positive electricity on that of the inside, separated by the glass, which is a bad conductor, and so prevents them from uniting. If the outside coating be connected with the knob by a good conductor, the electricities will rush together with a vivid flash. When the connection is made by means of the hand, we experience a shock, called the electric shock. The negative electricity on the outside of the glass, attracted and held by the positive of the inside, is said to be bound, and electricity so bound receives the name of statical. It is now the general impression that the electricities are confined to the surfaces of the glass jar, instead of to the tin-foils, and that the coatings serve merely as conductors. The coatings, when removed from the charged jar, give no evidence of free electricity. When restored to the jar, it is found that the jar is still charged. When the Leyden-jar will receive no more electricity from the prime conductor, it is said to be charged or saturated.

The Leyden-jar had not only an accidental but a very simple origin. Cuneus, of Leyden, in 1746, while trying to electrify a glass of water with a wire charged with electricity, holding the glass in one hand and removing the wire with the other, felt a sharp shock. The hand holding the glass acted as the outer coating, and the water the inside coating, of the Leyden-jar. The electrified wire charged the jar, and when the hand touched the water in withdrawing the wire, connection was formed between the outside and inside coating, completing the circuit and discharging the jar.

A number of Leyden-jars, so arranged that all the outsides are united and the insides connected by means of the knobs, form an electric battery. The battery may be discharged by connecting the inside with the outside of any single jar. A battery thus arranged gives great quantity, but, if the outside coating of each in succession be connected with the inner coating of the next, and the battery be discharged by joining the outer coating of the first with the inner of the last, great intensity is obtained.

Often it is inconvenient, and sometimes even dangerous, to discharge an electric battery by the hand, so that a discharging rod is used, consisting of two brass arms terminating in large brass knobs, and joined together by a hinge. The arms are provided with glass handles.

The electricity is confined entirely to the surface of the electrified body. This is easily proved by exciting a hollow cylinder of brass, and introducing into its interior an electroscope. The interior will not give the faintest trace of excitement.

The quantity of electricity depends altogether upon the superficies, and is not influenced by the mass. The greater the surface over which a given quantity or amount of electricity is spread, the less the potential, or tension, of the fluid. When two large globes of brass of equal size are insulated, and one of them is charged and then connected with the other, it is found that the charge is equally divided between the two, and that the potential, or tension, of either one is only one half of that of the originally charged globe.

On a spherical surface the tension of the electricity is uniform, but electricity concentrates on points or projections. A prime conductor having a number of points will soon part with its electricity, the air carrying it off rapidly from the points.

A jet of steam issuing from a boiler will generate large quantities of electricity. Armstrong contrived a steam electric machine of wonderful power, and called it the hydro-electric machine. It is safe, however, to let this apparatus alone; for there is always imminent danger of an explosion.

Is electricity a material substance, a single or double fluid, or a property of matter? The real nature of this subtile agent is unknown. In a latent state, it pervades all substances without affecting their volume or temperature, without adding to or subtracting from their weight; nor does it interfere with the power of cohesion in bodies. There are two theories of electricity that have much prevailed—the one of Dr. Franklin, and the other of Du Fay. According to the Franklinian hypothesis, there is a single, highly elastic, imponderable fluid pervading all matter. In the unexcited state, it is uniformly distributed through bodies. When a body becomes electrified, it either loses or gains more than its normal amount of the fluid. Thus, when glass is rubbed with silk, the glass becomes over- and the silk under-charged. A body overcharged is said to be in the positive, and undercharged in the negative state. The theory of Du Fay supposes two of these subtile fluids existing in combination in all substances, when in the natural or unexcited condition. These fluids are self-repellent, but attract each other. The friction of two bodies, such as glass and wool, separates the fluids, the glass taking one and the wool the other. These fluids receive the names of vitreous and resinous. In favor of the two-fluid theory, it may be remarked that, when a charge is passed through a card, there is a burr on both sides, showing the action of a double force; also, that the shape of the spark of positive electricity is a brush; of the negative, a star.

Dr. Faraday thought electricity a mere power of matter, like the attraction of gravitation; and spent much of his time trying to show that light, heat, and electricity were all modifications of one common principle. The conviction that electricity is a wave of polarization, passing along conductors, seems now to prevail with philosophers.

CHAPTER V.

ATMOSPHERIC ELECTRICITY.

Ordinarily, in clear weather, the atmosphere is found to be slightly charged with free positive electricity. The first evidence of this condition of the air is detected by the gold-leaf or other electrometer, at the height of about four feet from the ground. The electricity of the four feet of intervening atmosphere is disguised, or neutral, like that of the glass between the outside and inside coating of a Leyden-jar. When the atmosphere has free positive, the earth's surface is found to have free negative, electricity; this is the consequence of induction, but whether it is the action of the air on the earth, or of the earth on the air, is not so evident. Peltier attributes it to the earth's surface having always some free negative excitement.

As we ascend upward, the electric tension gradually increases. An innumerable number of methods have been employed for testing the electric state of the atmosphere at all altitudes. An ingenious test was made on the Great St. Bernard, by shooting an arrow attached to a long cord covered with tinsel, in different directions. The cord was also connected with a stationary gold-leaf electrometer. When the arrow was shot in a horizontal direction, the leaves were unmoved, but when in a vertical one, the leaves parted more and more as the arrow flew upward. The ordinary way of testing the electric condition of the air is by means of a long vertical pole, bearing a wire attached to an electrometer.

The electric potential of the air is weakest before sunrise, and strongest just after sunrise; it then diminishes and reaches its weakest point once more a few hours before sundown, after which it a second time increases until, during the night, it again attains its strongest point, and then decreases until near morning. The tension is greatest in fogs, and during frosty weather, and least in hot weather and just previous to rain. Atmospheric electricity is far more intense in winter than in summer, and seems to grow in force with the growth of the cold.

When the sky is overcast, and the clouds are moving in different directions, the electric condition of the air varies, and sometimes very rapidly. Now it is negative, and in a few moments positive, and different strata lying very close together may have different electric states. There are a great many different opinions concerning the cause of this free electricity in the air. The matter is very unsettled. Scientists have as yet arrived at nothing definite, some alleging one cause and others another.

A combination of the causes may be the nearest to the truth. Combustion on the earth's surface, evaporization, animal and vegetable life, chemical action, friction of the air against the ground, and the unequal distribution of heat in the different strata of the air, may each, in all probability, add its *pro rata* to the electric storehouse of the clouds.

A cloud is a vast collection of minute hollow vesicles of water, and is a fair conductor of electricity. Because they are good conductors, and so gather up the loose electricity, clouds usually contain a considerable quantity of it in the free state. When clouds differently charged come close together, they neutralize one another by a vivid flash. This is the lightning-flash. When an overcharged cloud is neutralized by the earth, the lightning-flash is between the cloud and the earth. This is the flash that works mischief, and which is so much dreaded.

Dr. Franklin was the first to prove the identity of lightning with electricity. This he did at Philadelphia, in 1752. Every one, of course, is familiar with the story of Franklin's kite. It was fashioned after the manner of an ordinary kite; silk, however, being used instead of tissue-paper. Connected with the string, and extending above the head of the kite, was a pointed iron wire. A key was attached to the lower end of the string, and to this key was tied one end of a short silk ribbon, whose other end was fastened to an upright post. The silk, being a non-conductor, insulated the string. This insulation was necessary; otherwise the electricity would be conducted off imperceptibly. When the storm-cloud came on, the string was saturated with rain, and became a good conductor, so that the electric fluid ran down it, and, with a vivid flash, leaped to any conductor approached toward the key. A short time afterward, Romas, in France, by using a much longer string, received from the storm-clouds vivid electric flashes, ten feet long, accompanied by reports as loud as that of a pistol. Professor

Richmann, of St. Petersburg, in 1753, experimented during a thunder-storm with a long, pointed conductor reaching high into the air. The professor made the insulator eight feet long, and, standing too close to the terminus of the conductor, a great charge passed through his head, singeing his waistbands, bursting open his shoes, and killing him instantly.

Two clouds, differently charged, act on one another by induction similarly to the coatings of the Leyden-jar, the air separating them taking the place of the glass. When they approach sufficiently close that the electric tension is powerful enough to overcome the resistance of the non-conducting medium between, the opposite fluids unite by a flash. A cloud and the earth act similarly, when the cloud approaches near enough to the earth. Clouds part with their charge to the earth at various heights, all depending on the force of their electric tension. Lightning has been observed to dart to the earth from thunder-clouds having a vertical height of 26,650 feet, and these clouds have been known to be only 83 feet from the ground when they emitted their spark.

Though the vesicles of the cloud are similarly electrified, they do not repel one another, because of the inducting influence exercised by the neighboring cloud or the earth. When a feather is placed on the prime conductor, its fine fibers fly apart, being similarly excited; but if the hand be approached toward the feathers, the repulsion disappears under the influence of the hand's induction, and all the fibers of the feather reach out in one direction toward the hand. The vesicles of a cloud in the vicinity of another cloud or the earth act similarly. Slate-gray clouds are negatively, and white, red, and orange-colored clouds positively electrified.

The lightning, or light, is caused by the resistance of the air to the passage of the electric discharge. The air being a non-conductor, electricity has to force its way through it with the greatest violence. This violent passage of the current through the air causes a wonderful compression of its particles, and this compression produces the vivid light. Lightning is merely a mechanical effect of the electric current. Lightning is principally of three kinds—zigzag, sheet, and ball lightning. The zigzag is caused by a discharge from a cloud at a great height from the earth. The fluid, in its downward journey, always seeks the path of least resistance. Moisture is a fair conductor, and, as the distribution of moisture through the air is very unequal, so the current, in following it, must take a zigzag course. The zigzag streak, meeting with more than ordinary resistance, is broken up into two, three, or more streaks. Sheet-lightning is a broad flash unaccompanied by sound, and, for the most part, is from one cloud to another, or is sometimes the reflection of distant lightning. It is also called heat-lightning, as it is said to presage heat.

Ball-lightning is a fearful thing indeed; much dreaded, and nobody knows precisely what it is. Many consider it a meteor that falls from the clouds during a more than ordinarily violent thunder-storm, and that it is not electricity at all. It is difficult, however, to understand how meteors can be so accommodating as to be on hand just when called for by these violent electric explosions. That this globular appearance is due to an uninterrupted discharge of electricity, is the most probable opinion. This glowing ball will set fire to any combustible material it happens to come in contact with; lightning-rods are no protection against it; and it occupies several seconds in its passage. This latter fact is the kernel of the difficulty. How lightning can consume several seconds in traveling over the space of a few miles, is inexplicable. Wheatstone, after much industry with a very delicate contrivance, made up his mind that the velocity of electricity is 288,000 miles per second, and no one ever estimated it below 13,500 miles; so that this phenomenon of the fire-ball has yet to be satisfactorily explained.

The distance of the lightning-flash can easily be computed by counting the number of seconds between the flash and the sound. The flash is instantaneous, while the average velocity of sound through the atmosphere at a temperature of 60° Fahr. is 1,125 feet per second. Ten seconds would show a distance of 3,750 yards, or more than two miles.

The thunder, most probably, arises from the vibrations produced in the air by its sudden and violent compression. The rolling is attributed to echo. But thunder rolls equally on the sea as on the land. Driven from echo, many philosophers try to account for the peculiarity of the reverberations by saying that, though the flash is instantaneous, still the sound, being so much slower, and breaking forth from all the points along the path of the flash, reaches the ear at different intervals. In this case, however, thunder should begin at its loudest and gradually die away; because the sound comes first from the nearest points, and then from points more and more distant. On the contrary, distant thunder is just audible at the beginning, gradually gains in strength, and again grows fainter, till it dies away. The best explanation yet ventured seems to be, that the zigzag course of the flash makes so many different angles that the waves of sound sometimes intermingle and sometimes interfere, weakening or strengthening each other, as the case may be. It is said that the sound of thunder has never been heard farther than fourteen miles from the flash, whereas the guns of Waterloo were heard 115 miles away. When a sharp, loud peal accompanies the flash, the stroke is in the immediate neighborhood.

Men and animals are known to have been killed, although at quite a distance from where the lightning actually struck. This is done by the returning shock. When a cloud is positively electrified, it induces negative electricity in the earth's surface beneath it, and also in all objects on that surface. When a cloud, consequently, is heavily charged with free positive electricity, a man just beneath it becomes strongly charged with the free negative fluid, owing to induction. Then, if a tree or other object discharge the cloud, restoring its electric equilibrium, there being nothing left in the cloud to hold the negative charge in the man, the negative rushes away from him with such violence as to kill him.

Lightning-rods, or paratonnerres, owe their origin to Dr. Franklin. Their purpose is to conduct the electricity from the cloud to the earth silently, imperceptibly, and harmlessly. Electricity always selects and follows the best conductor. The rod should be a good conductor, and attached to the walls by wooden fastenings. The rod being a much better conductor than the walls, trees, or air, will be selected by the electric spark. The rod must reach above the building to be protected, be strictly continuous, with good and perfect joinings, and run down a considerable distance into the moist ground. The best material is copper; but if iron, it must be at least three fourths of an inch in thickness. It should be pointed at the top, as points have an infinite power of conduction. If the joinings be poor, and the rod loosely put together, the current may leave it, and pass through the house. If the rod be too thin, it may be fused, in which case also the lightning may pass through the building. If there be metal gutters on the house, they should, for greater safety, be connected by metal strips with the rod. The ground end of the rod should run in a direction away from the building, penetrate at least six feet into the earth, and terminate in powdered charcoal, both to preserve it from oxidizing and to improve the conduction. The lightning-rod does not attract the fluid, but, when the charge must pass to the earth, the rod directs its course. The conducting power of the rod's point is so wonderful, that it disarms the cloud imperceptibly, stealing its thunder, and preventing a flash. The rod will protect a space all around, the shape of a cone, whose apex is the top of the rod, and the radius of whose base is twice the length of the rod. The most dangerous place to stand during a thunderstorm is under a tree or beside a tall building, for man being a better conductor than the tree or building, the current will leave these objects to pass through him. Man is a fair conductor, and will be selected by the fluid in preference to most substances, the metals excepted; and not being a perfect conductor, the fluid kills him. Lightning runs down the outside of a tree, because it is a better conductor than the inside; and the inside of a man, because the fluids of the body are better conductors than the skin. When lightning strikes a man or an animal, it kills, because of the violence of the shock to the nervous system. In a house unprotected by a lightning-rod, the safest thing to do is to lie down in a feather-bed in the middle of a room in the middle story. Feathers are non-conductors, and the position is out of the lightning's course. The attic and cellar are places of danger, as the fluid sometimes flashes from the earth to the cloud, and sometimes from the cloud to the earth; so that these places may be directly in its course. Standing near the fireplace, in a draught near an open window or door, leaning against a wall, are also attended with more or less danger. Smoke is a conductor, and may carry down the fluid into a person's body. The lightning may run down the walls of a house, or the large timbers near the open door or window, and so leave these to pass through the human body.

To be in a crowd of persons or near a herd of animals is dangerous, as the ascending vapor is a good conductor, and so many bodies offer a large conducting space. The best place for a person outside would be twenty-five or thirty feet from a tree, lofty building, or stream of water. Lightning seldom damages ships or steamboats, because water is so excellent a conductor, and the vessels so poor, that the fluid will not be diverted by them from its course; and they will not be struck, unless they are in the direct line of the flash.

Lightning is entirely too much feared; the risk of being killed by its stroke may be said to be infinitely small. There is far more danger to be encountered in the ordinary walks of life. The electric flash purifies the air, by generating nitric acid and ozone, or tritoxide of hydrogen. Both these substances have a tendency to destroy animal and vegetable putrefactions. The electricity of the atmosphere has a wonderful influence on both the animal and vegetable kingdoms, directly affecting the nervous system and the circulation of organic juices. Much of the stimulant we experience on a frosty morning is due to the extra quantity of electric excitement produced by the friction of the wind against the frosty ground.

As Dr. Franklin gave the first impetus to the study of atmospheric electricity, the next chapter will be devoted to that great *savant*.

CHAPTER VI.

BENJAMIN FRANKLIN.

BENJAMIN FRANKLIN, our own dear philosopher, was born in Boston, January 17, 1706, of Josiah Franklin and Abiah Folger, youngest daughter of Peter Folger, one of the first settlers of Nantucket Island. At the time of Benjamin's birth his father was a soap-boiler and tallow-chandler, though his ancestors, for upward of three hundred years, were village blacksmiths in Old England. His father was very poor, and had seventeen children to support, yet it seems they were all happy. Jane, the favorite sister of Benjamin, said of their early home: "It was, indeed, a lowly dwelling we were brought up in, but we were fed plentifully, made comfortable with fire and clothing, had seldom any contention among us; but all was harmony, especially between the heads, and they were universally respected."

Benjamin was early set apart by his parents for the Church, and with this view was sent, when eight years old, to the Boston Grammar-School. In less than a year he reached the head of his class. His father, however, after mature thought, changed his intention of devoting his son to the service of religion, being of opinion that the members of the ministry in America were too poorly recompensed. Accordingly, he was withdrawn from the Grammar-School, and sent for a year to George Brownwell, a master skilled in arithmetic and penmanship. This ended his school career, and when only ten years old his father took him into his own business of soap-boiling, which business the little Benjamin very heartily despised. His two earliest passions were for books and swimming. He was never excelled as a swimmer, and he may be said to have devoured books. He had the precious faculty of extracting from a book the one thing to which it owed its value. Among his first readings were Burton's "Historical Collections," Plutarch's "Lives," and Defoe's "Essay upon Projects."

Seeing his growing fondness for books, and his persistent dislike to his father's shop, his parents concluded to give him a trade kindred to his tastes. In his twelfth year he was apprenticed for nine years to his brother James, who was a printer. This James Franklin, August 17, 1721, published a small newspaper, called the "New England Courant." It is easily understood that a newspaper was at that time a rarity and a risk, when it is considered that the first London newspaper appeared in 1622, the first French one in 1632, and the first American, at Boston, on the 25th of September, 1690. The young Benjamin had a great ambition to become a good English writer. All his leisure moments on work-days and the greater part of Sunday were given to study, and he contributed several pieces surreptitiously to the "Courant." When his brother discovered that he was the author of these contributions, which were of considerable merit, he became quite incensed against him, and thenceforth treated him with great harshness.

In 1723, being in his eighteenth year, Benjamin resolved to no longer bear his brother's continued ill usage, and, without the knowledge of his family, ran away to New York. Here failing to obtain employment, after some rough experience and much fatigue, being penniless, he made his way to Philadelphia. In this city, after a short struggle with adverse circumstances, he obtained work at the printer's trade. The unworthy Governor of Pennsylvania, Sir William Keith, lured the young man from his work, and sent him, with false promises of assistance, to England, to purchase a printer's plant, that he might set up in business for himself. On reaching London, he discovered the perfidy of his supposed benefactor, and finding himself in a strange country, without friends, and with no means of returning home, he sought, and fortunately found, employment at his trade. He worked in London for a year and a half, and then returned to Philadelphia in company with a merchant named Denham, with whom he had contracted a close friendship. On reaching Philadelphia, Denham employed him as a clerk. Soon after, on the death of this merchant, he lost his clerkship, and returned to his old business of journeyman printer. About this time he started the celebrated club called the Junto, its object being the mutual self-culture of mechanics. It became very famous. In the spring of 1728, Franklin, by the aid of a few kind friends, was enabled to start a printing-office of his own.

His wonderful industry, great tact, and scrupulous honesty won success. Besides printing, he cast types, cut ornaments for title-pages, made his own ink, and even the lamp-black for the ink. Such unflagging energy as his must always prosper. One of his neighbors remarked of him at this time: "The industry of that Franklin is superior to anything I ever saw of the kind. I see him still at work when I go home from the club, and he is at work again before his neighbors are out of bed." Franklin published the "Pennsylvania Gazette," October 2, 1729. This undertaking almost overwhelmed him, and it required two years of most severe and incessant struggle to reach a position of financial safety. In those days of Franklin's youth it was truly a difficult task for a poor young man to win his way to prosperity. On September 1, 1730, he wedded Deborah Read, a truly noble woman, who proved a precious helpmate to him. Shortly after his marriage, he founded the Library of Philadelphia, one of the most useful institutions of its kind that ever existed; and so great and lasting was its success that, in 1861, it contained seventy thousand volumes.

In December, 1732, Franklin first published his almanac containing the sayings of "Poor Richard," which became famous all the world over. In 1736 he was elected Clerk to the General Assembly, and the following year appointed Postmaster of Philadelphia.

Amid all his arduous duties he was carrying on the work of mental and moral self-improvement with the greatest assiduity. In his seventy-ninth year, Franklin wrote: "It may be well my posterity should be informed, that to this little artifice, with the blessing of God, their ancestor owed the constant felicity of his life down to the seventy-ninth year, in which this is written. What reverses may attend the remainder is in the hand of Providence; but if they arrive, the reflection on past happiness enjoyed ought to help his bearing them with more resignation. To temperance he ascribes his long-continued health, and what is still left to him of a good constitution. To industry and frugality, the early easiness of his circumstances and acquisition of his fortune, with all that knowledge that enabled him to be a useful citizen, and obtained for him some degree of reputation among the learned. To sincerity and justice, the confidence of his country, and the honorable employs it conferred upon him; and to the joint influence of the whole mass of the virtues, even in the imperfect state he was able to acquire them, all that evenness of temper and that cheerfulness in conversation which makes his company still sought for, and agreeable even to his young acquaintance."

It was Franklin's virtue, more even than his great erudition, that made him revered and beloved for four generations. In 1744 he founded the Philadelphia fire system, which, under his guidance, soon attained great excellence. In 1746 Franklin began his studies and experiments in electricity. Electricity was then the rage throughout the civilized world. Cuneus, of Leyden, had just discovered the principle of the Leyden-jar. Franklin received from one of his friends in England a glass tube for generating the electric fluid. The tubes then used were two feet and a half long, and the rubber either cloth or buckskin. He devoted himself unreservedly to the study of this subtile agency. In 1747 he wrote: "I never was before engaged in any study that so totally engrossed my attention and my time as this has lately done; for, what with making experiments when I can be alone, and repeating them to my friends and acquaintance, who, from the novelty of the thing, come continually in crowds to see them, I have, during some months past, had little leisure for anything else." He frequently experimented with points, whose great power to draw off the fluid from bodies greatly engaged his attention. One of his first conjectures was, that electricity was not created, but only collected, by friction, and he soon reached his positive and negative theory; or, that electricity is a single subtile fluid, existing in all bodies, latent when unexcited, but, when these bodies are excited, having more or less than their normal quantity. Owing to his isolation from European philosophers, and unacquainted with their discoveries, he made many beautiful experiments, which, although previously made by them, were original with him. In 1749 he drew up a series of fifty-six observations, entitled "Observations and Suppositions toward forming a new Hypothesis for explaining the Several Phenomena of Thunder-gusts." The most celebrated of all his electric writings soon followed, and that which made his name forever famous in the world of science: it was entitled "Opinions and Conjectures concerning the Properties and Effects of the Electrical Matter, and the Means of preserving Buildings, Ships, etc., from Lightning, arising from Experiments and Observations made at Philadelphia, 1749." The two suggestions that will connect the name of Franklin for all time with electricity are included in one short passage. After detailing the results of an experiment, in which a miniature lightning-rod had conducted away the fluid from an artificial thunder-storm, he says: "If these things are so, may not the knowledge of this power of points be of use to mankind, in preserving houses, churches, ships, etc., from the stroke of lightning, by directing us to fix, on the highest part of those edifices, upright rods of iron made sharp as a needle, and gilt, to prevent rusting, and from the foot of those rods, a wire down the outside of the building into the ground, or down round one of the shrouds of a ship, and down her side till it reaches the water? Would not these pointed rods probably draw the electrical fire silently out of a cloud before it came nigh enough to strike, and thereby secure us from that most sudden and terrible mischief?"

He gives the steps by which he proved the identity of lightning and electricity. "Electrical fluid agrees with lightning in these particulars: 1. Giving light. 2. Color of the light. 3. Crooked direction. 4. Swift motion. 5. Being conducted by metals. 6. Crack or noise in exploding. 7. Subsisting in water or ice. 8. Rending bodies it passes through. 9. Destroying animals. 10. Melting metals. 11. Firing inflammable substances. 12. Sulphureous smell."

He had labored indefatigably in this science for six years, and had already convinced himself of the identity of the electricities of the clouds and the machine, before he made his kite-experiment in the spring of 1752. His son, then a young man of twenty-two years, was his only witness of the experiment. Just before the approach of a thunder-storm, he raised the silken kite on that part of the Philadelphia commons corresponding to the present corner of Race and Eighth Streets. The experiment proved a complete success, and made Benjamin Franklin the happiest philosopher in Christendom.

The philosophers of France were the first to recognize the value of Franklin's discoveries, and many similar experiments were made by them, confirming the truth of his results. He was now elected a member of the Royal Society of England, and awarded the Copley medal. Yale and Harvard Colleges conferred upon him the degree of Master of Arts. He founded, about this time, the University of Pennsylvania and the Pennsylvania Hospital. Franklin was the first to discover that plaster of Paris is a fertilizer. He first detected the poisonous properties of air exhaled from the lungs, and was the first to write effectively upon ventilation.

Franklin's political career began when he was forty-six years of age. He became successively justice of the peace, a member of the Common Council, an alderman, and a member of the Assembly. He was not an orator, but he was effective as a speaker through his inimitable power of illustration and the weight of his character.

Having held the place of Postmaster of Pennsylvania for sixteen years, he was appointed, in 1753, Postmaster-General for America. He greatly improved the postal service, and some of his improvements remain a part of the United States system to this day.

In 1756 Franklin was chosen agent to Great Britain for the Province of Pennsylvania, and immediately set out for England. On his arrival in London, he received congratulatory letters from the electricians of France, Germany, Holland, and Italy.

In London he continued to prosecute with vigor his researches in electricity; and in the spring of 1759, while on a visit to Scotland, the degree of Doctor was conferred upon him by the University of St. Andrews. During this visit, the Scotch paid him great honor, the corporation of Edinburgh giving him the freedom of the city. Nor did he neglect the other sciences. He rendered valuable assistance to Adam Smith in his "Wealth of Nations." He experimented much on heat and its conductors. One of these experiments in caloric he describes in this simple style: "I took a number of little square pieces of broadcloth from a tailor's pattern-card, of various colors. There were black, deep blue, lighter blue, green, purple, red, yellow, white, and other colors, or shades of colors. I laid them all out upon the snow in a bright, sunshiny morning. In a few hours, the black, being warmed most by the sun, was sunk so low as to be below the stroke of the sun's rays; the dark blue almost as low, the lighter blue not quite so much as the dark, the other colors less as they were lighter;

and the quite white remained on the surface of the snow, not having entered it at all. What signifies philosophy that does not apply to some use? May we not learn from hence, that black clothes are not so fit to wear in a hot, sunny climate or season, as white ones?"

After an absence of six years, he returned to his home in Philadelphia, November 1, 1762. New complications arising between the Governor and Assembly, Franklin was almost immediately reappointed English agent for the Province of Pennsylvania. His brilliant examination at the bar of the House of Commons, and his strenuous efforts for the repeal of the Stamp Act, had the effect of repealing that truly obnoxious measure. Georgia, New Jersey, and Massachusetts soon after appointed him their London agent. Finding his endeavors fruitless to arrest the quarrel between England and her American colonies, he returned to Philadelphia in 1775, after an absence of ten years. Franklin's reputation was at this time very great and extensive. He was incomparably the foremost man of America, a member of every important learned body in Europe, a manager of the Royal Society of England, President of the American Philosophical Society, and one of the eight foreign members of the Academy of Sciences of France. Three editions of his philosophical works had appeared in Paris, and a beautiful new and enlarged edition in London.

After the Declaration of Independence by the United Colonies, Franklin was appointed minister by Congress to represent this country at the French court. He devoted his whole heart and all his great mental power to obtain the aid of France in behalf of his beloved and struggling country; and succeeded in inducing that government to form an offensive and defensive alliance with the States.

His renown in France was marvelous. M. Lacretelle, the French historian, says of him: "Men imagined they saw in Franklin a sage of antiquity, come back to give austere lessons and generous examples to the moderns. They personified in him the republic, of which he was the representative and the legislator. They regarded his virtues as those of his countrymen, and even judged of their physiognomy by the imposing and serene traits of his own. Happy was he who could gain admittance to see him in the house which he occupied. This venerable old man, it was said, joined to the demeanor of Phocion the spirit of Socrates."

"Franklin's reputation," says John Adams, "was more universal than that of Leibnitz or Newton, Frederick or Voltaire; and his character more beloved and esteemed than any or all of them."

On the 20th of January, 1783, Franklin had the supreme happiness of signing, together with John Adams and John Jay, on the part of the United States, a treaty of peace with Great Britain. This ended the war between these countries.

Franklin was at this time the most distinguished man in Europe. He was the first to discover that the atmosphere of Europe is damper than that of America, and he was led to this observation from the uniform shrinking in America of the wooden instrument-cases made in Europe. He was the first to perceive that the Gulf Stream is warmer than the surrounding ocean, and that this stream is not phosphorescent.

In the spring of 1779 Dr. Franklin read a paper on the aurora borealis before the French Academy of Sciences. This is considered one of the best of his scientific writings. He attributes the aurora borealis to electricity. The following are the essential points of this paper: "Water, though naturally a good conductor, will not conduct well, when frozen into ice by a common degree of cold; not at all, where the cold is extreme. 2. Snow, falling upon frozen ground, has been found to retain its electricity, and to communicate it to an isolated body, when, after falling, it has been driven about by the wind. 3. The humidity contained in all the equatorial clouds that reach the polar regions, must there be condensed and fall in snow. 4. The great cake of ice that eternally covers those regions may be too hard frozen to permit the electricity, descending with that snow, to enter the earth. 5. It will therefore be accumulated upon that ice."

Sir Humphry Davy remarks of Franklin's electric writings: "A singular felicity of induction guided all Franklin's researches, and by very small means he established very grand truths. The style and manner of his publication on electricity are almost as worthy of admiration as the doctrine it contains. He has endeavored to remove all mystery and obscurity from the subject. He has written equally for the uninitiated and for the philosopher; and he has rendered his details amusing as well as perspicuous, elegant as well as simple. Science appears in his language in a dress wonderfully decorous, the best adapted to display her native loveliness. He has in no instance exhibited that false dignity, by which philosophy is kept aloof from common applications; and he has sought rather to make her a useful inmate and servant in the common habitations of man, than to preserve her merely as an object of admiration in temples and palaces."

A curious anecdote is told by Parton, his biographer, of a consequence of his constant love of experimenting: "While living in France, he sometimes extemporized an Æolian harp by stretching a silken string across some crevice that admitted a current of air. On revisiting a village, after the lapse of several years, he found the house in which he had formerly lodged deserted, from its having gained the ill repute of being haunted. Strange, melodious sounds, he was told, could be heard in its empty rooms. On entering the house he found some shreds of the silk still remaining, which had caused all the mischief."

Dr. Franklin returned to Philadelphia in 1785, after an absence in France of nine years. On his return, he was elected three times successively President of the Supreme Executive Council for the city of Philadelphia, was one of the principal framers of the Constitution of the United States, and retired from public life in 1788. At eleven o'clock at night, April 17, 1790, surrounded by his family and intimate friends, he departed this life, aged eighty-four years, three months, and eleven days.

Benjamin Franklin was a noble patriot and truly great philosopher; great as a man of business, a man of science, and a statesman. Well has a famous Frenchman said of him, "Eripuit cœlo fulmen, sceptrumque tyrannis" (he snatched the thunderbolt from the sky, and the scepter from tyrants).

CHAPTER VII.

GALVANISM, OR THE ELECTRICITY OF CHEMICAL ACTION.

In 1790, Galvani, in experimenting with the legs of a frog, observed that, when two different metals, as copper and iron, one touching the nerves and the other the muscles of these legs, came in contact, it caused the most violent convulsions and twitchings in the limbs. Galvani located this electrical excitement in the legs themselves, believing that the contact of the metals simply discharged the electricity of the legs, and thus produced the convulsions.

Volta, of Pavia, in 1792, attributed the electric development to the contact itself of different metals, and succeeded in producing an electric current by replacing, between the metals, the limbs of the frog by a moistened cloth.

Fabroni, of Florence, in the same year, first suggested chemical action as the generator of the electricity in these experiments.

When a small strip of copper and one of zinc are placed in a glass vessel containing acidulated water, so long as the metals are held upright and apart, no action is perceptible, nor is there any evidence of electric excitement; but so soon as the metals are joined together, or connected by a wire or other good conductor, it is instantly noticed that bubbles of hydrogen gas are given off at the copper plate; while, if a magnetic needle be held close to the connecting wire, it will be disturbed, or, if an electroscope be made a part of the circuit, it will give evidence of the presence of electricity. This simple arrangement is called a galvanic pair. The electric action will continue as long as the metals are connected; but, if the connection be broken, the action will instantly cease. The acid used in this simple experiment is dilute sulphuric acid, one part of acid to eight or ten parts of water. The action begins at the bottom of the zinc plate. The zinc decomposes the dilute acid, taking the acid with its negative electricity, forming sulphate of zinc; the positive of the zinc combining with the negative of the acid, setting the negative of the zinc free, which runs up the zinc plate, and manifests itself at the external end of that plate, thus forming the negative pole of the pair. In the mean time, the action of the zinc on the dilute acid sets its hydrogen free in a polarized state, its positive pole facing toward the copper. This liberated hydrogen attacks the neighboring atom of the dilute acid, taking the acid with its negative electricity, and setting the hydrogen free, with its positive pole directed as before. This particle of hydrogen attacks the next atom of acid, and so on, until the copper plate is reached, when the hydrogen, having no affinity for the copper, escapes in bubbles; previously, however, the positive of the hydrogen takes the negative of the copper, setting its positive free, which, running up the copper plate, forms the positive pole of the pair. This whole action is in the nature of convection, and is entirely invisible; the escape of the hydrogen bubbles at the copper pole and the gradual waste of the zinc being alone perceptible.

The zinc is the active principle of the pair, and called the electro-positive element; the copper serving only to gather and conduct the electricity, and called the electro-negative element. If, after the pair has operated for some time, the copper be taken out and weighed, it will be found to have lost none of its weight; the zinc, on the contrary, will be found to have lost in weight, having been dissolved by the acid to form sulphate of zinc. In forming a pair, it is necessary to choose two metals having different oxidizable powers; that is, one must have a greater affinity for the acid employed than the other. Thus, if copper had the same affinity for combining with sulphuric acid that zinc has, there would be no electrical development. If two plates of zinc were used, or two plates of copper, there would be no evidence of electrical excitement. The electromotive force of a pair, as it is called, or its power to generate electricity, is the difference between the affinity of the zinc and that of the copper for the acid; for copper has an affinity for sulphuric acid, as well as the zinc, though in a less degree, and the difference of these affinities constitutes the strength of the pair.

The more dissimilar the metals are in this respect, the greater will be the electro-motive force of the pair. Thus, zinc and silver would be much more powerful than zinc and copper, because the silver has less affinity for the acid than the copper; and zinc with platinum would be still better.

If strong water of ammonia had been used instead of dilute sulphuric acid, the copper and zinc would change places: the copper, having a greater affinity than zinc for the ammonia, would become the electro-positive element and the negative pole of the pair. So that, in judging of the behavior of a galvanic pair, the liquid, as well as the metals, must be considered.

In all cases where zinc is used for galvanic purposes, it is amalgamated, or coated with mercury. The zinc of commerce is so very impure that the acid acts upon it incessantly, even when disconnected with the other metal, or when no current is flowing, thus unnecessarily wasting it away by local action. This local action takes place and consumes the zinc, without the generation of electricity for the common current. To prevent this local action and reduce the surface of the zinc to one uniform electric condition, the zinc is amalgamated. This protects the zinc from the action of the acid, until connection is formed between the metals, or until and during the passage of the electric current. The zinc is amalgamated by rubbing on the mercury with a brush or cloth, or simply by pouring a small quantity of mercury into the acidulated water, and it will of its own accord amalgamate the zinc.

While a positive electric current is passing from the zinc to the copper by way of the liquid, and thence back to the zinc through their points of contact, a negative current is passing in the opposite direction from the copper to the zinc. We have the most positive evidence of the passage of these currents. If the metallic strips be four inches long and two broad, and connected by a piece of very fine platinum wire half an inch in length, the wire will become brilliantly ignited, from the electric discharge taking place through it; and this wire will retain its brilliancy so long as the chemical action continues. The metal strips are called the electro-motors. Though other bodies than metals may be used as electro-motors, still metals are the best. When zinc and copper are used as the electro-motors, zinc is the generator, and is called, as before stated, the electro-positive element, but is the negative pole. When copper and silver are used, copper is the generator, and so the electro-positive element, and negative pole. The behavior of a metal depends altogether upon the nature of the other metal used with it—the metal more readily oxidizable being the electro-positive element, or negative pole of the galvanic pair. In the following list, any metal, when used with the ones succeeding it, will be the electro-positive element, and the electro-negative with any preceding it: zinc, lead, tin, iron, copper, silver, gold, platinum, and charcoal. The further apart they are in this list, the more powerfully will they act together. The strongest combination is zinc and charcoal.

Muriatic acid, common salt, or other liquid compound that acts upon zinc, may replace the sulphuric acid. The quantity of electricity evolved increases with the surface exposed to the action of the fluid in which it is immersed. The best way to construct a pair is to have the copper in a circular form surrounding the zinc, as in this way all the evolved electricity is gathered up and utilized. Galvanic electricity is also called dynamic, or electricity in motion, in contradistinction to frictional, which is said to be statical, or bound. This distinction is not, however, of an absolute character, because frictional electricity sometimes forms a current, as in its passage from the cushion of the electric machine to the earth, and galvanism may be made to overcome slight resistances. Still, frictional electricity is noted for its tension, and galvanism for its quantity. The quantity of galvanic electricity is increased by increasing the exposed surfaces of the metal electromotors, but its tension is increased by joining together several galvanic pairs. In using several pairs together, the zinc of one pair should be connected with the copper of another, and the zinc of this with the copper of the next, and so on, until the zinc of the last pair is reached, which should be connected with the copper of the first.

The single pair produces a greater effect upon the needle, and has a greater heating power; while the combination has a higher tension, and greater power to decompose chemical compounds. No single pair can impart a shock or decompose a fluid. The current of the combination seems to owe its intensity to the momentum imparted to it by the overcoming of the resistances of the many liquids, or media, through which it has to force a passage.

In the very best arranged galvanic pairs or combinations the whole of the generated electricity is not gathered into the current. The strength of the current suffers from one loss or another. Professor Ohm, of Nuremberg, has mathematically investigated the force of currents, and supplied us with the laws governing their transmission. Supposing S to represent the actual strength of the current at the end of the conducting wire; F, the whole electric force generated by the dissolving of the electro-positive element; R, the resistance of the fluid contained between the metals to the passage of the current; E, the external resistance from conducting wire; then Ohm's simple but celebrated formula is:

$$S = \frac{F}{R + E}$$

If R be very small compared with E, R may be omitted, and the formula is reduced to

$$S = \frac{F}{E}$$

The resistances of wires of the same material and of uniform thicknesses are in the direct ratio of their lengths, and in the inverse ratio of the squares of their diameters. Thus, a wire of a certain length offers only one half the resistance of one twice its length; and a wire of a certain diameter will offer four times the resistance of one of twice its diameter. The longer the wire, the greater the resistance; the thicker the wire, the less the resistance.

Almost from the very birth of galvanism, there have been two theories claiming to account for its cause. They are called the contact theory and the chemical theory. Those who maintain the former say that the electricity is produced by the simple contact, or touch, of the heterogeneous metals. The latter theorists attribute the presence of the electricity to the chemical affinity of the acid for the metal. The supporters of these theories have waged a lively war from the beginning. An experiment of Faraday's has done a great deal toward establishing the chemical theory. He used platinum and iron as the metals, and sulphuret of potassium as the liquid. When the wires were connected, there was not the faintest evidence of electricity; but when a cloth moistened with dilute sulphuric acid was placed just between the connecting wires, an electric current was instantly perceived to pass. When the zinc and copper are simply touched together, without the employment of acid, or even water, we may presume that there is some feeble (very feeble indeed) chemical action, owing to the affinity of the oxygen of the air for zinc. Hence, it is almost evident that the origin of galvanism is chemical action.

A galvanometer is an instrument for measuring the strength of a galvanic current. The astatic galvanometer is sufficiently sensitive for ordinary purposes, and is thus constructed: Two compass needles are joined together, one above the other, but perfectly parallel, and having their poles diametrically opposite. This double needle is suspended by a silk thread within a glass case, with the lower needle running along inside an oblong coil of wire, in the same direction as the wire. The lower needle has been let into the coil by means of a slit in the coil, and the upper needle runs over a graduated scale. When a current of electricity runs along a wire parallel to a compass-needle, the needle is deflected from its meridional direction to the right or left, according as the current is positive or negative. Ampère gives the following rule: "Suppose the diminutive figure of a man to be placed in the circuit, so that the current shall enter by his feet and leave by his head; when he looks with his face to the needle, its north pole always turns to his left." The wire in all cases is supposed to run along in the direction of the magnetic meridian. When a single electrified wire thus runs over and parallel to a needle, it will slightly deflect the needle; and, if the same wire is bent and doubled back under the needle, the deflection will be doubled, according to Ampère's rule. The greater the number of wires, the greater the deflection; so that a coil will produce a considerable deflection. The directive force toward the north being also absent in the double needle, the sensitiveness of the instrument is greatly enhanced. The degrees on the graduated scale show the comparative strength of currents.

The voltameter is an apparatus invented by Faraday, for the purpose of measuring the strength of currents. This is a most perfect test of a current's power, and is considered absolute. Two small pieces of platinum are placed in a bottle containing water slightly acidulated with sulphuric acid. Wires are soldered to the platinum pieces, run up through the cork of the bottle, and terminated in binding-screws. The bottle has a tube running up through another part of it, into a trough of mercury. A glass tube filled with mercury, having a graduated scale, empties into this trough of mercury. When the binding-screws are connected with a galvanic circuit, the water is decomposed in the bottle into its elements of oxygen and hydrogen. These gases escape up through the trough, and into the tube containing the mercury, and forcing out the mercury, occupy its place in the top of the tube. The graduation shows the amount of gas set free, by any strength of current, in any given time.

CHAPTER VIII.

GALVANIC BATTERIES.

The combination of several galvanic pairs forms a galvanic battery. Volta constructed the first battery, which was also called a "pile," from the peculiarity of its formation. It consisted of alternate plates of zinc and copper, with the interposition of layers of cloth saturated with acidulated water. The series proceeded in this wise: Copper, zinc, cloth; copper, zinc, cloth; and so on, through thirty or forty alternations. The first copper must be connected by wire with the last zinc, to complete the circuit. The generation of the current, in Volta's arrangement, depends on chemical action. When the moisture of the cloths has completely evaporated, the action ceases. To make up for the evaporation of the moisture in the voltaic pile, Cruikshank constructed a battery in which zinc and copper are soldered together in hollow squares, and placed in a wooden trough. All the zincs face one way, and the coppers the opposite; and the trough is filled with dilute sulphuric acid —one part acid to sixteen of water, for weak action. The last zinc is joined to the first copper.

Smee's battery consists of two thin rectangular plates of zinc, clamped to a piece of non-conducting wood. Between the zinc plates is placed a small silver slip, running into a groove in the wood. The zinc and silver are insulated from one another. Both the zinc and silver, however, have binding-screws, and can be joined by a conducting-wire, when so desired. The clamped plates are placed upright, in a glass cell containing a single fluid, dilute sulphuric acid, one part acid to eight or ten parts water. The silver, in this arrangement, takes the place of the copper in the simple pair, and acts as the positive pole of the battery.

Bubbles of hydrogen gas adhere with great tenacity to smooth, polished metallic surfaces, and thus ordinarily interfere with the action of the battery, by forming a film of gas between the silver and the acid, and so impede the usefulness of the battery. To obviate this drawback, the surface of the silver is roughened, by throwing down on it, by means of a galvanic current, platinum, in a state of fine division, called platinum-black. By this means the surface of the silver presents an innumerable number of small points, from which the bubbles of hydrogen are readily given off, thus facilitating the action of the battery. This is a very cheap battery, very easily managed, and is constant for a long time.

In batteries where a single fluid, as dilute sulphuric acid, is used, the escape of the hydrogen at the positive pole greatly impedes and enfeebles their efficiency. By using a metallic oxide, the metal will be replaced in combination by hydrogen, and so the metal, instead of hydrogen, will be carried over, and precipitated on the copper plate. Dilute sulphuric acid should be near the zinc, and the oxide near the copper. To prevent the fluids from mixing up, and so bringing the oxide into the neighborhood of the zinc, and thus retarding its activity, two cells must be employed, one for the acid and the other for the oxide.

Daniell's battery is made up of an outer cylindrical cell of copper, in which is placed a smaller cell of porous earthenware, and in this a solid cylinder of amalgamated zinc. Into the outer cell of copper is poured a solution of sulphate of copper, and into the porous vessel containing the zinc, dilute sulphuric acid, one part acid to eight of water. To complete the circuit, a wire connects the zinc with the copper.

The acid in the porous cell attacks the zinc, forming sulphate of zinc, and the hydrogen being set free, is driven, by the influence of convection, through the porous cell, in among the sulphate of copper, which it decomposes, taking the oxygen, producing water, and precipitating metallic copper in bright crystals, with positive electricity, upon the copper plate. Daniell's is the most useful battery for telegraphic purposes, on account of its cheapness, easy management, and great constancy.

In telegraphic offices the ordinary form of Daniell's battery differs some little from the above; the outer cell being of glass, into which a hollow cylinder of zinc is set, and into this the porous cell, with a solid rod of copper. The copper is immersed in sulphate of copper solution, and water simply is poured into the outer cell containing the zinc. The water surrounding the zinc becomes in a short time acidulated, the acid of the sulphate permeating the porous cylinder. In the copper cell of this battery some pieces of solid sulphate of copper, the blue vitriol of commerce, are placed on a perforated shelf, in order to sustain the saturation.

This battery of Daniell has some drawbacks, the chief of which is that, after long-continued action, copper works its way to the porous cell, where it is deposited, closing the pores and impeding the passage of the hydrogen.

Several improvements have been made upon this battery, without, however, altering the principle of action. Siemens-Halske's is a modification of Daniell's, the diaphragm dividing the cells being a preparation of paper, instead of the porous earthenware.

The Meidinger battery is also a modification of Daniell's, the porous cell being replaced by a glass funnel, through an aperture in which the sulphate of copper passes slowly down by its own weight into a copper vessel. This copper vessel is located at the bottom of a much larger glass vessel, filled with a solution of Epsom salts, and also containing a disk of zinc.

The gravity battery is another modification of Daniell's, and is constructed on the principle that sulphate of copper is heavier than sulphate of zinc. In the bottom of a large glass cell is placed a circular disk of copper, on which is poured a solution of sulphate of copper; over the solution of sulphate of copper is poured a solution of sulphate of zinc, and in this last fluid is immersed a zinc disk, with fixtures to attach it to the top of the glass. The solution of sulphate of zinc is so much lighter than that of sulphate of copper, that the former fluid will remain on the top.

This arrangement requires the most delicate nursing. It will not suffer the merest movement without mixing the fluids; and it must be kept in a dry, warm place.

The Menotti, Sir William Thomson's, and the Muirhead batteries act on the Daniell principle.

Grove's platinum battery is the most powerful and energetic of all galvanic contrivances. The outer vessel is a glass cylinder containing a hollow roll of amalgamated zinc. Within the zinc is a porous earthenware cell, in which is placed a small strip of platinum. The platinum, being so very costly, is placed on the inside for economical purposes. The outer cell contains dilute sulphuric acid, and the inner cell concentrated nitric acid. When connection is made

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between the metals, the sulphuric acid, as usual, attacks the zinc, forming the sulphate of that metal, and the free hydrogen passes, by convection, through the porous cell, and decomposes an equivalent of nitric acid, which readily yields up its oxygen to the hydrogen; the deutoxide of nitrogen then rises to the surface of the fluid, and takes two equivalents of oxygen from the air, forming nitrous acid, which escapes in the form of red fumes.

Though eminently energetic, this battery is very expensive, very difficult of management, and unhealthy, owing to the poisonous properties of the escaping nitrous acid.

Bunsen's battery is composed of an outer cell of carbon, prepared from pulverized coal and coke, about ten inches in height and five inches in diameter. A porous cell of earthenware, containing a solid cylinder of amalgamated zinc, is placed within the carbon cell. Connection is made with the carbon cell, by running a wire around on its outside. Dilute sulphuric acid is poured into the cell having the zinc, and strong nitric acid into the carbon one. The carbon takes the place of the platinum in Grove's, and acts the part of the negative element or positive pole. This is an intensely powerful battery, and has the advantage of cheapness. It can not, however, compete with Grove's, being unsteady in its work, owing, perhaps, to the earthy matter found in the carbon, and rendering it a bad conductor.

The chromic acid and Marié-Davy batteries are modifications of the Bunsen battery. In the former, the nitric acid is replaced by a mixture of bichromate of potash and sulphuric acid; and in the latter the zinc stands in water, and protosulphate of mercury is substituted for the nitric acid.

The unit of the electro-motive force of a battery is called a volt, and is about seven per cent less than a single Daniell's cell. The unit of resistance is called an ohm, and is about four hundred and six feet of the ordinary telegraph wire, known as number eight. The unit of the strength of a current is called a farad, and is the amount of electricity that flows, in the space of a second, from a cell whose electro-motive force is a volt, through a wire whose resistance is an ohm.

The relative electro-motive forces of the principal batteries are as follows: Grove's, 1·92; Bunsen's, 1·88; Daniell's, 1·079; and Smee's, 0·47.

When points of prepared carbon are attached to the ends of the wires connecting the poles of a powerful galvanic battery, and then brought together, intense heat and light are instantly produced. It is necessary, however, to join the points, before the phenomena of heat and light are perceptible. Once the connection is made, the points may then be withdrawn to a short distance, and the flame will still continue, forming itself into the shape of an arch, much broader at the negative than the positive pole. The carbon of the positive pole consumes much more rapidly than that of the negative, particles of the carbon being carried from one pole and deposited on the other. If a very powerful Grove or Bunsen battery be employed, the arch may be lengthened out some inches. The galvanic circuit produces the most intense heat in nature this side the sun, and the light is the most brilliant artificial light known. The most refractory metals yield to this heat, steel and platinum readily fusing, and even undergoing volatilization, when subjected to its influence. By combining several hundred Grove or Bunsen cells, the diamond may be volatilized. The galvanic light resembles very closely the light of the sun, and can be used for photographic purposes. This light is not the effect of combustion, for it may be produced in a vacuum, under water, or in a gaseous atmosphere that does not support combustion.

As the carbon points gradually wear away, and thus increase their distance apart, the light, after a short space, suddenly goes out. To obviate this, and render the flame continuous, an ingenious piece of mechanism is used to move the points forward in proportion to their exhaustion, and so hold them regularly at the one distance.

Each of the metals, when deflagrated by the galvanic current, has its own peculiar color. Gold burns with a vivid white light, silver with an emerald green, copper and tin with a pale bluish, lead with a purple, and zinc with brilliant white.

CHAPTER IX.

ELECTRO-CHEMICAL DECOMPOSITION, ELECTROTYPING, AND GILDING.

THE galvanic current has been of the greatest use in chemistry, in decomposing compound bodies into their elementary constituents. It was by this means that Davy reduced the metals potassium, sodium, calcium, magnesium, and others from their alkalies, potash, soda, lime, and magnesia. If the wire that completes a galvanic circuit be parted in the middle, and the ends tipped with platinum, and then introduced into a vessel of water, oxygen gas will bubble up at the positive end, and hydrogen at the negative. The water is decomposed into its elements of oxygen and hydrogen. If graduated glass tubes, filled with water, be let down over the ends of the wire, oxygen will rise in one end, and hydrogen in the other, expelling the water.

Twice as much hydrogen as oxygen, by volume, should be given off in the same time, because water is composed of two measures of hydrogen to one of oxygen. In actual experiment, however, it is found that a little more than twice as much hydrogen as oxygen is given off, because oxygen, being soluble in water, loses some little in being dissolved by the water.

It seems that the positive wire decomposes an atom of water, the oxygen escaping into the air, producing a bubble; the hydrogen is at the same time set free and polarized, and attacks the neighboring atom of water, taking its oxygen, forming water, and setting hydrogen free, which, being polarized, attacks the next atom of water, and so on, until the last atom of hydrogen escapes at the negative wire, also producing a bubble. If copper, or other oxidizable metal, had been the terminus of the positive wire, instead of platinum, the oxygen would have united with such metal, forming its oxide, and thus preventing the oxygen from being given off. A great many other substances besides water are decomposed in this way.

Dr. Faraday, to whom this branch of the science of electricity is greatly indebted, has introduced some Greek terms, which, being widely used, need some explanation.

This manner of decomposition is itself called electrolysis, from *electron*, signifying electricity, and *luein*, to loose or dissolve. The substances to be decomposed are called the electrolytes, from *electron*, as before, and *lutos*, dissoluble. The ends of the wire are said to be the doors through which the electricity flows, and hence are called electrodes, the Greek *hodos* meaning a way or path. The elements of the decomposition are called ions, from the Greek participle *iōn*, going, from the fact of these elements going to the positive or negative electrode. The electrodes are also called the anode and cathode, the positive being the anode, from *ana*, upward, and *hodos*, way, or the upward way, or the way the sun rises; and *kata*, downward, and *hodos*, way, or downward way of the sun.

The galvanic current does not decompose bodies in the solid state; it is necessary that the electrolyte, in order to suffer decomposition, be reduced to the liquid state either by solution or fusion. For instance, the chlorides of lead, silver, and tin must be fused, in order to become fit subjects for the decomposing influence of the galvanic current. Some liquid compounds also are unaffected by the current, refusing to conduct it, such as a solution of ammonia; some others conduct the current well enough, and still are not decomposed by it, as, for example, sulphuric acid.

When compound solutions are submitted to the influence of the current, the electro-negative elements invariably go to the positive electrode, and the electro-positive go to the negative electrode. In the electrolysis of muriatic acid, sulphate of copper, nitrate of lead, chloride of sodium, or iodide of potassium, the iodine, chlorine, sulphuric and nitric acid, are set free at the positive electrode; and soda, potash, hydrogen, copper, and lead, at the negative.

All bodies have what are called equivalents, or atomic weights, that is, the proportionate weight in which they unite with other bodies. All bodies will suffer a decomposition, by the same strength of current in any given time, proportionate in amount to their atomic weight. For instance, a galvanic current, sufficient to decompose 9·01 grains of water, will in the same time decompose 58·78 grains of chloride of sodium, 163·28 of sugar of lead, 79·88 of blue vitriol.

The amount of decomposition is always directly proportioned to the quantity of electricity that passes through the electrodes, and hence electrolysis is a true measure of electricity.

A great deal of galvanic action is often wasted on electrolytes that are poor conductors, as they impede the progress of the current. The addition of a liquid that is a good conductor sometimes greatly facilitates the work of the current. Water is a poor conductor, and the passage of a current through it is usually slow, but if a little sulphuric acid be added, the decomposition of the water becomes much more rapid, and the current utilized to its utmost. In decomposing water, if, instead of collecting the gases in separate tubes, they be collected into a single receiver, and an electric spark passed through them, they will explode, forming water. It is found that the quantity of electricity generated by the decomposition of a single grain of water will be just sufficient to recombine an amount of oxygen and hydrogen to form one grain of water, or, there is an exact correlation between these forces.

Electrotyping is the process of depositing upon any surface a coating of metal from one of its metallic solutions by means of a galvanic current.

Copies of the most delicate medals or engravings can be thus produced in gold, platinum, silver, copper, zinc, tin, lead, cobalt, nickel, brass, or bronze. Even the delicate tracings of Daguerre's exquisite pictures can be perfectly copied by this method. Every line, and even the shades of polish of an engraving, may be accurately reproduced.

In considering the action of a Daniell's cell, it was noticed that the sulphate of copper was decomposed through the agency of the current, and metallic copper precipitated on the copper plate. The copper plate of the battery is thus covered with a film of bright, crystalline, malleable copper, which may be easily removed. This film is found to be an exact fac-simile of the copper, every tiniest scratch being copied. It was this observation that led to electrotyping.

If the wires from the poles of a Smee's battery be immersed in a vessel containing a solution of sulphate of copper, the copper will go to the negative electrode, and the acid to the positive one. If a copper cast of a medal or engraving is sought, the model is suspended in the solution from the negative electrode, while the positive electrode is simply immersed in the solution.

All parts of the model not desired to be copied are covered with a resinous varnish, or some similar non-conductor. If the surface to be copied, such as a cast of wax or sulphur, be a non-conductor, it may be made a conductor by a thin layer of powdered plumbago. The thickness of the film, or coating, is proportioned to the length of time the battery is operating. Thus, the electrotype can be made as thick or as thin as required.

In this way copper electrotypes are taken of the map-plates of the Coast Survey of the United States, saving an immense amount of expense, and preserving the original plate. The original plate is never printed on, as a few hundred impressions on paper would be sufficient to render it useless, by obliterating the delicate lines of the engraving. The first impression or the first electrotype copy is in relief, and, to obtain an exact fac-simile, the electrotype must itself be electrotyped.

If, instead of sulphate of copper, a solution of chloride of gold be placed in a glass vessel, or earthenware trough, and the wires of a Smee's battery introduced, the gold will go to the negative electrode, and the chlorine to the positive.

In this way the baser metals may be covered or tinted with the precious, in a permanent and perfect manner. A coating of gold, thinner than the thinnest gold-leaf, can be laid on by this process, or, if desired, may be made several inches in thickness. The surface to be gilt must be suspended from the negative electrode, being first cleaned with great care, in order that the gold may adhere.

If, instead of chloride of gold, the trough contains a weak solution of cyanide of silver in cyanide of potassium, surfaces may be plated with silver. It is necessary to first clean the surface with warm caustic potash, and then wash it with nitrate of mercury. The nitrate of mercury leaves a thin film of mercury behind it on the surface, and this acts as a cement between the article and the silver. The thickness of the silver plating will depend on the length of time of immersion. In this process of plating, a piece of silver is attached to the positive electrode, and the article to be plated to the negative. During the action, the silver of the cyanide is deposited on the article fixed to the negative electrode, while the cyanogen passes, by convection, to the positive electrode, where it attacks the silver there suspended, and forms with it cyanide of silver, thus dissolving the silver, and keeping up the saturation. In this way a piece of silver of any shape or form may be converted by the galvanic current into a uniform plate or covering.

CHAPTER X.

GALVANI AND VOLTA.

Luigi Galvani, who has given his name to the electricity of chemical action, was a famous physicist of Bologna, where he was born on the 9th of September, 1737. Galvani followed the profession of medicine, in which he attained to eminence. He studied under the renowned masters Beccaria, Tacconi, and Galeazzi. He was very devout, especially in his youth, and early resolved to study for the Church, but friends dissuaded him from the step.

Galvani was elected Professor of Anatomy in the Institute of Bologna in 1762. Here his lectures were remarkable for their clearness and accuracy, and he won great popularity. He also wrote several scientific works, the chief of which are "Considerations on the Urinary Organs," and "On the Organs of Hearing of Birds."

Galvani, however, is indebted to his wife for the immense celebrity his name has reached. She was the daughter of the eminent medical professor Galeazzi, and was a woman of superior mind and vast attainments. She was the real discoverer of galvanism, and is, indeed, the mother of the modern science of dynamic electricity.

While preparing frog-legs, she noticed that they became wonderfully convulsed when placed, by accident, on a scalpel in contact with a charged electric machine. She informed Galvani of her discovery, who forthwith began a series of experiments in electricity, which he continued through many years, inspiring thereby others, and particularly Volta, to pursue with ardor this science under its new form. As a consequence, the science of electro-dynamics gradually grew and developed.

In some of his later experiments, Galvani produced the convulsions and twitchings of the frog-legs, without the aid of electricity, by simply touching the nerves with one metal, and the muscles with a different one, and joining the metals. Galvani insisted that the electricity resided in the limbs, the metals merely acting as conductors of the fluid.

Volta, on the contrary, argued that the electric excitement was owing to the simple contact of dissimilar metals. They were both but partly right, as it is now generally conceded that the current is generated principally by chemical action.

Galvani's views on electricity are contained in his principal work, which is a commentary, "De Viribus Electricitatis in Motu Musculari." Galvani died in his sixty-first year.

One of the most illustrious electricians of all time was Alessandro Volta, a native of Como, and born in 1745. In 1774 he reached the chair of Physics at Pavia. His labors in electricity were truly indefatigable. Starting from the crude experiments of Galvani on the frog-legs, he gradually advanced to the construction of his "pile," which is a complete and perfect galvanic battery. It is said to be the greatest invention of a single mind the world ever saw.

He was invited by Napoleon Bonaparte to Paris, to exhibit the working of his "pile" to the French Institute. Napoleon enrolled him in the Legion of Honor, conferred upon him the order of the Iron Crown, and the titles of Count and Senator of the Kingdom of Italy.

Volta, in opposition to Galvani, maintained the contact theory, as it is called. He believed that the galvanic current owes its origin to the simple contact of dissimilar metals, ignoring both the animal theory of Galvani, as also that of chemical action.

Volta was the inventor of the electrophorus, the electrical condenser, the hydrogen-lamp, the electrical pistol, and the eudiometer, for testing the purity of the air.

Volta was the recipient of distinguished honors from his own and other countries, and departed this life in his eighty-first year.

CHAPTER XI.

ELECTRO-MAGNETISM.

PROFESSOR OERSTED, of Copenhagen, is the father of the science of electro-magnetism. Although he had, for twenty years, suspected the relation between magnetism and electricity, it was not until 1819 that he discovered the law governing electro-magnetic attraction and repulsion, and then fell upon it by the merest accident.

When a wire bearing a galvanic current is extended in a direction parallel with the magnetic needle, but in the plane above it, the north end of the needle will be deflected to either side of the magnetic meridian, depending on the course of the current. If the current's direction is from north to south, the north pole of the needle will be driven toward the east; if this direction is from south to north, the needle's north pole will vibrate to the west, the degree of deflection depending on the proximity and strength of the current.

If, instead of running along in the plane above the needle, the wire be placed in the plane beneath it, the reverse of the above takes place: the current entering from the north sends the needle's north end westward; and coming in from the south, the north of the needle is driven eastward.

Ampère has left an easy formula, by which the direction is always remembered: Let any one suppose himself to be lying in the direction of the positive current, his head representing the copper, and his feet the zinc, and looking at the needle, its north pole will always move toward the right hand.

If a conducting wire be bent into the shape of a rectangle, and the needle placed between its horizontal branches, by referring to Ampère's formula it will be seen that the top and bottom currents tend to deflect the needle in the same direction, thus giving a double force to this tendency. By multiplying the folds of the wire, a most sensitive means of detecting the presence of an electric current has been devised, by the ingenuity of Schweigger. Schweigger's instrument, improved by Chevalier Nobili, has been already described as the astatic galvanometer. The influence of the current on the needle diminishes inversely as the square of their mutual distances, for very short wires; but, when the wire's length is considered infinite, the intensity of its attraction is simply in the inverse ratio of the distance.

The third law of motion is, that when one body acts upon another, action and reaction are equal and in opposite directions. If the magnetic needle had been stationary, in the above instances, and the wire free to move, the movements of the wire, in virtue of this third law of motion, would be, by reaction, in strict accordance with the principles governing the conduct of the needle.

Wires conducting galvanic currents moving in the same direction, attract one another; and in opposite directions, repel.

Experiment has fully proved that the force by which the electric current acts on the magnet is neither that of attraction nor repulsion, but tangential, its tendency being to cause the poles of the magnet to revolve about the wire in opposite directions, until a state of equilibrium is reached, where the action of one pole just balances that of the other. Taking advantage of this principle, Dr. Faraday, by ingeniously contriving to confine the action of the current to one pole, was enabled to produce a rotary motion of the magnet.

If a bar of soft iron be inserted in a spiral-shaped coil of wire, and the two ends of the wire connected with the poles of a galvanic battery, the bar will be instantly converted into a magnet, but will lose its magnetism when the circuit is broken. If, instead of soft iron, a piece of steel be used, the magnetism acquired will be permanent. In this spiral coil, commonly called a helix, the wire should be covered with a wrapping of silk, or very fine cotton thread, to prevent the spirals from attracting one another, and drawing so closely together that there is danger of the current flashing from one end to the other, without passing around the whole coil.

The position of the poles in this temporary or electro-magnet depends on the direction of the current. If the soft-iron bar in the helix stands north and south, and a current from the copper plate of a battery be passed around it from north to south, in a direction opposite to the apparent motion of the sun, the north end of the bar will be a north pole and the south end a south pole, as may be perceived by its attracting the opposite poles of a magnetized needle. But, if the passage of the current corresponds with the sun's apparent path, the south end will be the north pole, and the north end the south pole of the bar.

The helix, during the passage of the current, assumes magnetic properties, and, if freely suspended, will place itself in the direction of the magnetic meridian. In this position it will present all the properties of a magnetized needle, being attracted by the opposite, and repelled by the same pole of a magnet.

If a fine needle be inserted in the helix, it will be equally attracted by all parts of the spiral at the same time, and so place itself unsupported in the center of the helix, like Mohammed's fabled coffin.

The iron bar should be so placed in the helix that its axis will be at right angles to the direction of the current. The farther the bar is removed from this position, the more its magnetic intensity diminishes.

Electro-magnets may be made far more powerful than any natural magnets. The intensity of an electro-magnet is, in a great measure, determined by the strength of the current, and the number of the convolutions in the helix. When the iron core of the helix is very thin, there is a limit to the number of convolutions, beyond which no increase in magnetic force is gained. The greater the number of folds, the greater the resistance offered to the passage of the current. So that there is a fixed relation between the number of convolutions and the strength of the current, that should not be deviated from, in order to secure the maximum magnetic intensity. The maximum of magnetic force in different magnets is proportioned to the area of section, or to the square of the diameter of the core.

The usual form of the electro-magnet is still called the horseshoe, although it has departed quite considerably from the horseshoe-shape. It consists of a flat rectangular base of soft iron down into which are screwed two cylindrical soft-iron rods, one near each end of the base, and not exceeding four inches in length. Thick helices of insulated copper wire are put down over these uprights. The wire is coiled in the helices in the same manner as if there had been but one straight, continuous bar. An armature of very soft iron is placed over the poles of this magnet. The softer the iron of the armature the better, that the magnetism may instantly vanish, on the breaking of the circuit. A magnet of this kind, with a powerful battery attachment, may be made to sustain thirty-five hundred times its own weight, or a matter of several tons.

The celerity with which the soft iron becomes magnetic, on closing the circuit, and loses its magnetism on breaking it, has been utilized to produce, automatically, extremely rapid motion. As an instance of this automatic action, suppose one plate of a battery to be connected with the wire forming the helix of an electro-magnet, and thence connected with a brass upright. To this brass upright is fastened a horizontal metallic spring, which holds up the armature of the electro-magnet with sufficient force, when the circuit is open, to press it against an adjustable screw joined by wire to the other pole of the battery. The passage of the current magnetizes the electro-magnet, which draws down the armature from its contact with the screw, and thus severs its connection with one pole of the battery, breaking the circuit. The electro-magnet loses its magnetism, the circuit being broken, and ceases to attract the armature, which is then thrown up, by the action of the spring, against the screw, again closing the circuit, and magnetizing the electro-magnet, which draws down the armature, breaking the connection, and so on, producing of its own accord a continuous and most rapid motion.

Dr. Faraday observed, in 1830, that a galvanic current traversing a wire will induce a momentary current in another wire lying alongside of it. This second wire is not connected with a battery, but should form a closed circuit. The induced or secondary current, as it is called, is in an opposite direction to the primary; it is merely a throb, that ceases instantly on the closing of the primary circuit. As long as the first current continues to flow, this secondary one gives no evidence of its existence; but, on the breaking of the primary current, the induced or secondary again appears, but only momentarily, and in the same direction as the primary. There are, then, two induced currents: one, on making the connection between the poles of a galvanic battery; and one, on breaking the connection. The current induced by closing the primary circuit is in a direction opposite to the primary, but the one induced by opening the primary is in the same direction as the primary.

It is found that the longer the wires of both primary and secondary circuits, within certain limits, the greater the strength of the induced current and the severer the shock it imparts. Advantage has been taken of this to construct electric machines to communicate shocks for medicinal and other purposes. One coil of wire is placed within another coil; the ends of the inner coil are connected with the poles of a galvanic battery, and the ends of the outer coil are held by the person to whom it is desired to impart the shock. As often as the circuit is closed or opened in the inner helix, an induced current is generated in the outer helix, which communicates a shock to the person in contact with its poles. In order to produce the shocks with sufficient rapidity, an automatic circuit-breaker, as already described, is attached to the battery circuit.

The induced current has the ordinary properties of the galvanic current, and has, moreover, great tension like static electricity.

It has been stated that so long as the primary current continues to flow there is not the least sign of electric excitement in the second wire after the first throb; but if the second wire is moved towards the wire conveying the current, an induced current is generated in the second wire, in a direction opposite to the primary current. If, instead of the second wire being moved toward the first, it be moved away from it, a secondary current is induced in the second wire, in the same direction as the primary current.

It is not necessary, for the purposes of induction, that the second coil should surround the first; it may only be laid upon it or above it. Nor is the effect confined to the second coil; but, if a third or fourth coil be connected with the second, currents of electricity will also be induced in them at each interruption of the battery-current. The currents in the several coils move in different directions.

When the battery circuit is closed, a current in the second coil moves in the opposite direction, called the initial current; and, when it is opened, the secondary current flows in the same direction, and is called the terminal current. The initial current will induce a tertiary current flowing in the opposite direction; and the terminal current, a tertiary current flowing also in an opposite direction. These tertiary currents can induce currents in other helices of a fourth and even the seventh order.

In the very same wire in which the current is traveling an induced current is produced, on closing the circuit, when the wire is coiled into a helix. This current induced in the same wire is called the extra current, and is in the opposite direction to the main current, and so impedes its passage and lessens its power. On breaking the circuit, an extra current is again induced, though in the same direction as the original current, thus adding to its strength. This is the reason why a greater shock is experienced, by a person holding the poles of an induction battery, at the breaking than at the closing of a circuit. Because of this extra current, the magnetism of an electro-magnet does not instantly vanish on the breaking of a circuit. It is thus owing to the existence of this extra current that the speed of an electro-magnetic motor can not be increased beyond a certain limit, and so can not be employed to any great advantage in mechanics.

The longer the wire, the greater the duration of the extra current, sometimes reaching as much as three quarters of a second, and hence telegrams can be sent far more rapidly along a short circuit than a long one.

The ease and celerity with which the electro-magnet takes up and lays down its magnetism renders it of supreme importance to telegraphy.

CHAPTER XII.

OERSTED AND AMPÈRE.

HANS CHRISTIAN OERSTED, the father of electro-magnetism, and a scientific discoverer of great fame, was a native of Denmark, and born in 1777. He won the degree of Doctor of Philosophy from the University of Copenhagen, in 1799, and immediately after began the profession of medicine.

In 1806 he was appointed to the chair of Natural Philosophy in the University of Copenhagen. His fame as a physicist, especially in the department of electricity, soon spread over Europe. His main efforts in science were directed toward proving the identity of magnetism, electricity, and galvanism. It was while engaged in experiments toward this end that he made his greatest discovery, that of electro-magnetism, the chief pillar of his reputation, and, in fact, one of the very greatest discoveries ever made in physical science.

Many honors were bestowed on Oersted for his brilliant discoveries. He was corresponding member of the French Institute, perpetual secretary to the Royal Society of Sciences in Copenhagen, a knight of the Order of Merit in Prussia, of the Legion of Honor in France, of the Danish Order of the Dannebrog, and a councilor of state.

Oersted was much honored by his country, both before and after his death, for it was apparent that his chief aim in life was to contribute to the improvement and well-being of his fellow-citizens.

André Marie Ampère, "the intellectual Ampère," as Humboldt named him, was born at Lyons, January 20, 1775. A shadow was thrown over his whole life by his father's tragic death, beneath the blade of the guillotine, in the Revolution of 1793.

Ampère was a very great mathematician and a most distinguished scientist. He was elected member of the Academy of Sciences in 1814, and in 1824 was appointed to the chair of Experimental Physics in the Collége de France. He labored hard to show the identity of magnetism and electricity, and his theory of electro-dynamics reached great fame.

Although Oersted was the discoverer of electromagnetism, Ampère was the great expounder of its laws. He was the author of the celebrated formula for determining the movements of the magnetized needle under the influence of the galvanic current.

Ampère contributed very valuable aid toward all the departments of electricity. He was an original thinker of great versatility, and an indefatigable laborer in the fields of electro-dynamics.

What was most admirable in Ampère was his disinterested love of science, which made him take almost as much interest in the discoveries and labors of other men as in his own.

He was a devoted Christian, and fulfilled all his religious obligations with fervor and simplicity. His distinguished son, after enumerating his claims to imperishable fame, ends with these words: "A true Christian, he loved humanity. He was good, simple, and great."

CHAPTER XIII.

THE ELECTRIC TELEGRAPH.

THE positive and negative electricities of a galvanic battery have a wonderful tendency to unite, and, when the opposite poles are joined by a conducting wire, these fluids flow together with inconceivable rapidity. It matters not how long this wire may be; provided it is a good conductor, they will traverse it with the same winged speed. Advantage has been taken of this attraction between the fluids, their great velocity, and the discovery of the electro-magnet, to devise a means of quick intelligence between distant stations.

The telegraph, from the Greek *tele*, far, and *graphein*, to write, is the medium of this communication. If the wire from the positive pole of a battery ran completely around the globe to join its negative pole, the current would travel the circuit in one second, were the wire's conductivity perfect.

When it is desired to send a signal to a distant station by means of the battery, the metallic circuit connecting the poles must reach there and back; a continuous wire must run from the positive pole to the station, and from the station back to the negative pole. The fluid will then pass over this distance and back, from one pole to the other, forming a complete circuit.

The principle of telegraphic signaling is quite simple. The wire from the positive pole of a battery is borne along over insulated supports to the distant station, where it is joined to the helix of an electro-magnet, and similarly borne back again to the negative pole of the battery, thus completing the circuit.

Since the celebrated discovery of Professor Steinheil, however, in 1838, that the earth is a perfect conductor, one of the wires has been dispensed with, the earth taking the place of the returning wire. To complete the circuit, under this consideration, the wire from the copper plate of a battery is extended on insulators to the distant station, there joined to the helix of an electro-magnet, and thence connected with a large copper plate sunk in the earth. The zinc element of the battery is in like manner joined by wire to a large copper plate, also sunk in the earth. It will be readily seen that there is thus a complete circuit between the copper and zinc elements of the battery, through the medium of the earth and the single wire. The positive electricity runs along the wire to the helix of the distant station, and thence, by way of the sunken copper plate, into the ground, and, by way of the earth, back to the sunken copper attached to the zinc, through which it reaches the zinc, thus completing the circuit.

Over the electro-magnet, at the distant station, is placed an armature attached to a lever moving vertically on a horizontal pivot, so that, when the armature is drawn down by the attraction of the electro-magnet, the opposite end of the lever is thrown up against a wooden roller. When the electro-magnet becomes demagnetized by the breaking of the current, it ceases to hold down the armature. There is a spring attached to the armature to draw it up, when freed from the attraction of the electro-magnet. The end of the lever that presses against the roller has a steel point precisely fitting into a delicate groove in the roller. Over this roller is carried a narrow paper tape in a regular and continuous manner, by means of clockwork.

At the sending-station there is a key inserted in the circuit, by which the current can be opened or closed at the pleasure of the operator. The key is a simple spring, which is pressed down by the operator's finger to complete the circuit, by establishing metallic communication between the poles of the battery.

When the sender presses down his key, he completes the circuit, the current passes over the wire to the distant station, magnetizes the electro-magnet, draws down the armature, and throws up the steel point against the paper tape passing along the roller. The steel point indents the paper tape, by pressing it into the groove upon this roller. So long as the current passes, the steel point presses the paper, making a continuous mark. As soon as the circuit is broken, the electro-magnet discharges its magnetism, and the steel point falls away from the paper and ceases to mark. The circuit being renewed, the point marks again; and this may be repeated as often as the operator pleases. The sender can break or close the circuit as often and as rapidly as he pleases, and it will be all recorded in proper shape at the receiving-station. The length of time that the circuit is closed will be exactly registered in the corresponding length of the mark made by the steel point. A touch will produce a dot, a continued pressure a long line, and intermittent repeated touches a series of dots and short lines. These easily form an alphabet. To complete the arrangement, the operator at each station must have his own key, as well as electro-magnet. The clock arrangement is so contrived that the attraction of the armature by the electro-magnet, on the first closing of the circuit, sets it in motion.

The telegraphist's alphabet is the offspring of a conventional arrangement of dots and dashes. The Morse system of telegraphy is superior to all others, its method of notation being by far the simplest and most complete.

The following are the Morse characters:

A - —
B — - - -
C - - -
D — - -
E -
F - — -
G — — -
H - - - -
I - -
J — - — -
K — - —
L ——
M — —
N — -
O - -
P - - - - -
Q - - — -
R - - -
S - - -
T —
U - - —
V - - - —
W - — —
X - — - -
Y - - - -
Z - - - -
& - - - -
1 - — — -
2 - - — - -
3 - - - — -
4 - - - - —
5 — — —
6 - - - - - -
7 — — - -
8 — - - - -
9 — - - —
0 ———

The wire connecting the stations should be as perfectly insulated as possible. It is the disposition of the electric fluids to unite by the nearest route. If the wire, before reaching its destination, should accidentally come in contact with the earth, the current, instead of passing all the way around, would speed back to the battery by this shorter path. The wire is usually strung to cedar or chestnut poles, by means of glass or porcelain connections. The average number of poles to a mile is thirty. In climates of uniform temperature so many are not requisite; but with us, owing to the great vicissitudes of heat and cold, there is often a variation of four feet per mile in the length of the wire, and the safety of the line calls for this number.

As in practice it has been found utterly impossible to perfectly insulate the wire, the strength of the current is continually ebbing away, passing in little streams into the earth; as a consequence, messages are never sent beyond fifty or sixty miles without the assistance of a local battery. Through the means of an electro-magnet, or relay, as it is called, the weak current of the main line opens or closes the current of the local battery, which then acts instead of the main current in working the receiver's armature.

The relay is simply an electro-magnet, which is placed in the main circuit, and performs the office of opening and closing the current of a local battery, at the receiving-station, which battery in turn works the register or sounder.

Some very limited telegraphic systems eliminate the earth connection, finding it more convenient to use a continuous metallic circuit, as, for instance, the municipal fire-alarm telegraph.

Iron wire, about one eighth of an inch in diameter, and weighing from three to four hundred pounds per mile, is universally used for telegraphic purposes. The wire is galvanized, to preserve it from oxidizing. The best wire is made from Swedish charcoal-iron. Copper is a better conductor than iron, in the proportion of six to one; but iron is much cheaper.

A switch is attached to every operator's key, to enable him to close the circuit when not working. When finished operating, he slides the switch in between the key and the wire, thus keeping the circuit constantly closed. This is called the closed-circuit plan, and is the one employed on all American lines using the Morse method.

The movement of the armature is confined within fixed limits by adjustable stops, and so regulated that the armature never altogether touches the electro-magnet. If the armature came into actual contact with the electro-magnet, it would not discharge its magnetism instantly on the breaking of the current, and so would impede the work of recording.

The paper tape, or register, is no longer employed in this country, except at very small stations. In all the large offices, the operators are so expert that they can read the message by the sound of the armature, and can so dispense with the register. The language of the instrument is so familiar to their ears that they write the message without hesitancy, in the ordinary letters of the vernacular. To facilitate this method, there is attached to the instrument a sounder. The armature is made quite heavy, and is operated by a strong local battery and relay, to give the stroke more volume. An arch or bridge is also provided, on which the stroke of the armature takes effect. The message is read from the spaces between the strokes, with which the ear of the operator becomes perfectly familiarized.

The studs of the key through which connection is made or broken are platinum, in order that they may not be oxidized or fused by the current's passage. This key makes the connection in as perfect a manner as if the wires themselves were brought into actual contact.

When the operator at one station wishes to transmit a message to another station, he removes his switch, breaking the current's flow. The armatures of the relays and sounders at both stations then fall off from their magnets. By breaking and closing the circuit so as to form the characters of the telegraphic alphabet, the armatures of his own and the distant sounder will respond to every movement of his key, and thus the message may be copied by the distant operator from his sounder. As the transmitter's own sounder answers to the movements of his key, the receiver may, at any time, interrupt him, by opening his switch and breaking the current. The sender is instantly notified of this interruption by the failure of his instrument to work.

A number of way-stations may be worked by one main line, provided each has its own relay and local battery. Twenty-five is about the limit, however, that can be advantageously so worked.

The battery used in telegraphy is, generally, some form of Daniell's. The gravity battery answers the purpose very well. Some telegraph companies are beginning to substitute induced electricity, instead of galvanism, for the working of their lines.

Several messages may be sent simultaneously over the same wire, by the use of proper mechanism. The best manner of quadruplex transmission is the invention of Prescott and Edison. Quadruplex telegraphy is the sending of four dispatches, two from each of two different stations, at the same time. The eminent electrician Prescott explains his system thus: "The distinguishing principle of this method consists in combining together two distinct and unlike methods of single transmission, in such a manner that they may be carried on independently upon the same wire, and at the same time, without interfering with each other. One of these methods of single transmission is known as the double-current system, and the other is the single-current or open-circuit system. In the double-current system the battery remains constantly in connection with the line at the sending-station, its polarity being completely reversed at the beginning and at the end of every signal without breaking the circuit. The receiving relay is provided with a polarized or permanently magnetic armature, but has no adjusting spring, and its action depends solely upon the reversals of polarity upon the line, without reference to the strength of the current. In the single-current system, on the other hand, the transmission is effected by closing and breaking or increasing and decreasing the current, while the relay has a neutral or soft-iron armature, provided with a retracting spring. In this system the action depends solely upon the strength of the current, its polarity being altogether a matter of indifference. It will, therefore, be apparent that, by making use of these two distinct qualities of the current, viz., polarity and strength, two sets of instruments may be operated at the same time on the same wire."

The power of sending any number of messages simultaneously on the same wire is only limited by the delicacy of the adjustments which each additional current would entail; any number of armatures may be attached to the same main wire, each so constituted as to be influenced differently by the current's flow.

There are other systems of telegraphy besides the Morse, but none so much in use.

A complex form of type-printing telegraph was patented by Royal E. House, of Vermont, in 1846. The Bain chemical telegraph, employing no electro-magnet, transmits its signals by the decomposition of chemically prepared paper.

The needle telegraph, depending on the deflection of a needle by the galvanic current, was invented by Baron Schilling in 1832.

Wheatstone's dial telegraph was invented in 1839.

David E. Hughes, of Kentucky, patented a type-printing apparatus in 1855.

Phelps patented an electro-motor printing instrument in 1875.

Telegraphic intelligence may be sent under the ocean, as over the land, provided the conducting wire receives proper insulation. The best material for the purposes of insulation thus far devised is gutta-percha, though even it is far from being all that could be desired. Insulation is the most difficult problem to be solved in telegraphy, gutta-percha having some serious defects. It dries up and cracks in sandy soil. It rots in very damp soil. It is easily damaged by the careless handling of workmen.

The first successful attempt to send the galvanic current under water was across the Hudson

River, between New York and Jersey City, in 1848. The first attempt at submarine cable-laying was in 1850, under the English Channel, between Dover and Calais. This first-born cable had but a day's ephemeral life. The next effort, however, made the following year, between the same places, was a complete success. All the waters of the world are now so girdled with cables that all peoples are in instant communion, through the electric telegraph.

CHAPTER XIV.

PROFESSOR MORSE.

SAMUEL FINLEY BREESE MORSE, the inventor of the electric telegraph, one of the greatest men of this century, was born April 27, 1791, at Charlestown, Massachusetts. He entered Yale College when he was in his fifteenth year. During his college-life his fondness for painting amounted to a passion, and he excelled in chemistry and mathematics. The celebrated Benjamin Silliman was his Professor of Chemistry.

Morse was graduated from Yale in his eighteenth year. He went to England in 1811 to learn painting, and put himself under the tutorship of Benjamin West and Washington Allston, both eminent American artists resident in London. He applied himself also to sculpture, and, in the year following his arrival in England, received from the hands of the Duke of Norfolk the gold medal, the prize offered by the Adelphi Society of Arts for the best single figure in sculpture.

In 1815, his money being exhausted, he departed from England and returned to America. For several years he obtained a very precarious livelihood, by painting portraits in Boston, Charleston, and New York. He founded the National Academy of Design in 1825, and became its first president. In 1829 he again visited Europe, to perfect himself in his art. After three years he returned to New York in the packet-ship Sully. It was during this homeward voyage that he designed the electric telegraph. He had, however, been previously for years a close student of electricity, and frequently attended the lectures of Professor Dana on electro-magnetism at the Athenæum.

The labors of Galvani and Volta had furnished a constant flow of electricity, and Oersted had supplied the electro-magnet, and thus were the elements ready at hand to be molded to the purposes of the telegraph.

Before Morse left the Sully he had not only devised, but perfected, in all its parts, his plan of a telegraph. All that is claimed for Morse is, that he linked together the great discoveries of other men, and fitted them to the purposes of commerce. Still, in this alone he performed a wonderful task, requiring a colossal brain and indomitable perseverance. Over thirty years after the invention of his first crude instrument, at a magnificent banquet given in his honor at Delmonico's, Professor Morse, in alluding to his telegraph, said: "In 1835, according to the concurrent testimony of many witnesses, it lisped its first accents and automatically recorded them, a few blocks only distant from the spot from which I now address you. It was a feeble child indeed, ungainly in its dress, stammering in its speech; but it had then all the distinctive features and characteristics of its present manhood. It found a friend—an efficient friend—in Mr. Alfred Vail, of New Jersey, who, with his father and brother, furnished the means to give the child a decent dress preparatory to its visit to the seat of government. These few facts suffice here to indicate the birth of the telegraph."

This Alfred Vail did, indeed, give efficient aid to the new invention. He improved very materially Morse's crude instrument, and supplied the telegraphic alphabet. Morse had also other valuable helpers.

During the latter years of his artist-life, Morse had a tremendous struggle for very subsistence. Portrait-painting was not a lucrative vocation at that time. An instance of his distress is told by one of his pupils, Colonel Strother. "I engaged to become," says the colonel, "Morse's pupil, and subsequently went to New York and found him in a room in University Place. He had three other pupils, and I soon found that our professor had very little patronage. I paid my fifty dollars; that settled for one quarter's instruction. Morse was a faithful teacher, and took as much interest in our progress, more, indeed, than we did ourselves. But he was very poor. I remember that, when my second quarter's pay was due, my remittance from home did not come, as expected, and one day the professor came in, and said, courteously:

"'Well, Strother, my boy, how are we off for money?'

"'Why, professor,' I answered, 'I am sorry to say I have been disappointed; but I expect a remittance next week.'

"'Next week!' he repeated, sadly; 'I shall be dead by that time!'

"'Dead, sir?'

"'Yes, dead by starvation!'

"I was distressed and astonished. I said hurriedly, 'Would ten dollars be of any service?'

"'Ten dollars would save my life; that is all that it would do.'

"I paid the money, all that I had, and we dined together. It was a modest meal, but good, and after he had finished, he said: 'This is my first meal for twenty-four hours. Strother, don't be an artist. It means beggary. Your life depends upon people who know nothing of your art, and care nothing for you. A house-dog lives better, and the very sensitiveness that stimulates the artist to work, keeps him alive to suffering.'"

Morse's struggle to have his invention recognized in a material way by Congress was a long and severe one. His faith in his invention, and his invincible perseverance, shine forth with brightest luster. He was ridiculed and rebuffed term after term of Congress. Still he persevered, until finally his friends succeeded in obtaining for him an appropriation of thirty thousand dollars. It was the last bill passed in the session of 1842. Just previous to the passage of the bill, Morse had given up all hope, and had withdrawn in despair.

The following legend is taken from "Harper's Monthly": "Morse made his preparations to return to New York next day, and, retiring to rest, sank into a profound slumber, from which he did not awake until a late hour on the following morning. But a short time after, while seated at the breakfast-table, the servant announced that a lady desired to see him. Upon entering the parlor he encountered Miss Annie Ellsworth, the daughter of the Commissioner of Patents, whose face was all aglow with pleasure.

"'I have come to congratulate you,' she remarked, as he entered the room, and approached to shake hands with her.

"'To congratulate me!' replied Mr. Morse, 'and for what?'

"'Why, upon the passage of your bill, to be sure!' she replied.

"'You must surely be mistaken; for I left at a late hour, and its fate seemed inevitable.'

"'Indeed, I am not mistaken,' she rejoined; 'father remained until the close of the session, and your bill was the very last that was acted on, and I begged permission to convey to you the news. I am so happy that I am the first to tell you!'

"The professor very heartily thanked her, and said: 'As a reward for being the first bearer of the news, you shall send over the telegraph the first message it conveys.'

"'I will hold you to your promise,' replied she. 'Remember!'

"'Remember!' responded Morse; and they parted."

In May, 1844, the line between Washington and Baltimore was completed, and the whole apparatus in working condition. The professor sent word to Miss Ellsworth to come and send the first dispatch. Accordingly, she sent the first regular telegraphic message ever conveyed between distant stations.

"What hath God wrought!" were the words of the dispatch.

On May 27, 1844, the news of the nomination of James K. Polk, by the Democratic Convention, was sent from Baltimore to Washington. From that time forward the telegraph grew rapidly into public favor. Besides conferring untold blessings on his race, Morse achieved a colossal fortune and immortal fame.

CHAPTER XV.

MAGNETO-ELECTRICITY—DYNAMOS.

FARADAY discovered, in 1831, that when the pole of a permanent magnet was inserted in a coil of wire, a current of electricity was induced in the coil at the instant of insertion. The current's existence, however, was but momentary. Also that another momentary current was induced in the coil, in the opposite direction, upon the withdrawal of the magnet. In these experiments, the ends of the coil were in contact with a galvanometer. So long as the magnet remained at rest in the coil, there was no evidence of electric excitement. There is thus a reciprocity between the magnet and the current. The magnet produces a current, and the current a magnet.

If, instead of connecting the ends of the wire with a galvanometer, they be held in the hands, and the magnet be repeatedly inserted and withdrawn, a series of severe shocks will be felt.

If an electro-magnet be rapidly revolved on an axis in front of the poles of a large permanent magnet, a series of induced currents will be manifested in the wire of the electro-magnet; for, when the poles of the electro-magnet come just opposite those of the permanent magnet, the electro-magnet will be magnetized, and induce a current in its helix. When the poles are separated by the revolution of the electro-magnet, the electro-magnet discharges its magnetism, and so induces a current in the helix, in a direction opposite to the previous current. There are thus in every revolution of the electro-magnet four induced currents, two in one direction and two in the opposite. The direction of the first current is governed by Ampère's for mula.

By constructing an apparatus in such a way that an electro-magnet may be rapidly revolved in the vicinity of the poles of a large fixed permanent magnet, with the addition to the axis of the electro-magnet of a commutator, or a break-piece composed of alternate ribs of copper and ivory, great streams of electricity, and in one direction only, may be generated. An instrument of this kind is called a magneto-electric or dynamo-electric machine, or simply dynamo for brevity. Dynamos are multiple in form, and have reached great perfection. Dynamo is from the Greek *dunamis*, power, and is applied to electricity in motion, in contradistinction to that in the bound or static condition. No battery can be constituted to compete with them in power; and they are much more economical and far less troublesome than batteries. Though differing much in model and variety of structure, all dynamos depend on the same principle of magneto-electric induction.

The dynamo answers all the purposes of the battery. Its electricity may be employed in electrolysis, physiology, lighting, motion, etc.

Saxton, Wilde, Siemens, and Wheatstone, were early in the field with machines. But Gramme, of Paris, has given us by far the most celebrated and, indeed, useful one of them all. His instrument supplies a powerful current and in a single direction, without the aid of commutators. Instead of an electro-magnet or other armature revolving before and in the immediate vicinity of the poles of a permanent magnet, the Gramme instrument has a wheel revolving vertically between the arms of a vertical permanent magnet.

This wheel acts the part of armature, and is composed of an annular band of soft iron, wound around with several separate bobbins of insulated copper wire, whose ends terminate in radial copper bands insulated from each other. This armature acts the part of a combination battery, each bobbin performing the office of a separate cell having its positive and negative poles. During the revolutions of the wheel, the electricity is carried off from each side of the vertical line by wire brushes. The vertical is the dividing line between the two halves of the circuit. A constant, steady, powerful current of electricity is thus generated. This dynamo can be made of any convenient size, and be driven by a steam-engine of any number of horse-powers.

A dynamo of late contrivance is that called the Ferranti-Thompson, and is remarkable for cheapness and simplicity of construction, but has the great drawback of having alternating currents.

The Ball unipolar dynamo-machine is another late invention, in which two armatures are used, and in such a way that only one pole of a magnet is presented to each. This apparatus requires the assistance of commutators, and demands a very high rate of speed.

The superiority of the Gramme dynamos rests in the low rate of speed necessary, and the freedom from commutators. Other dynamos require in the neighborhood of two thousand revolutions in a minute for effective work, causing thus a rapid heating up and wearing away of the machine. The Gramme dynamos can do all necessary work with a speed of three hundred revolutions in a minute, and generate a constant, even current, without commutators.

The dynamos thus far contrived are not well suited for telegraphic purposes, as the tension required to overcome the resistance of a long circuit would demand what as yet seems to be an impossible construction. Dynamos are available chiefly for electric lighting and electroplating.

If two dynamos are so employed that the current from the armature of one may pass into the armature of the other, the electricity generated by the motion of one will move the other. The dynamo may thus be used as a motive force, or electro-motor, as it is called. Dynamos are so used to work machinery and run cars. As an electro-motor, however, the dynamo must be said to be in its absolute infancy. The longest electric railway in the world is in Ireland, between

Portrush and Bushmills. This line is run by a stationary dynamo, and is six miles in extent.

The electricity is conveyed to the motor either through the medium of the rails themselves, one rail conveying the current to the motor, and the other rail conducting it back to the dynamo, or by means of an auxiliary conductor. This conductor runs along between and parallel to the rails, and the motor receives the electricity from it through a metal brush. This brush is connected with the motor, and presses upon the conductor. The current is conveyed back to the dynamo by way of the rails.

Electricians are very sanguine of the brilliant future in store for their cherished electro-motor. The entire absence of smoke and cinders will render it unrivaled for tunnel and underground travel; and, even in case of collision or other accident, a person will have the comfort of being killed without being previously scalded by glowing steam, or roasted by fiery coals!

CHAPTER XVI.

THE STORAGE OF ELECTRICITY.

By the storage of electricity is meant the accumulation of a quantity of electric energy, to be used afterward at will and to suit convenience. A storage-battery, also called a secondary battery, is, in truth, an apparatus for transforming electricity. It is not the actual collection of the fluid itself, after the manner of Leyden-jars, or prime conductors. Electricity can never be stored in this way for any useful or commercial purpose.

When we wind up the spring of a clock, the force or energy requisite to do so is stored away, to be used afterward in running the clock. When we turn a crank to draw up the iron hammer of a pile-driver, we have so much energy stored away, to be employed in driving down the pile. So, when, by the force of the electric current, we separate substances that have a great chemical affinity, the force being removed, these substances combine again, regenerating the same quantity of electricity that it required to separate them.

In mechanics it is often desirable to transform force into speed, or again speed into force. So, in electricity, tension may be transformed into quantity, and quantity again into tension.

Electric transformers are of two classes; one regards tension and the other quantity. The very life of the secondary or storage battery hangs on Newton's principle, "To every action there is an equal and contrary reaction." Without reaction we could have no storage of energy.

In a Daniell's cell zinc is eaten away, and pure copper deposited. By forcing a current of electricity back through the cell, the copper will be eaten away, and zinc deposited. In the deposition of the pure zinc, we actually store energy; for, when the pressure is removed, the affinity of the oxygen for the zinc being free to assert itself, will cause their reunion, and so will generate the same quantity of electricity that was required for the deposition.

The chemical affinity of the zinc for the oxygen is called its polarization. The force which separates the zinc from combination is called the electro-motive force; and the zinc's tendency to resist this force, or indeed its polarization, is called its counter-electro-motive force. The storage of electricity is the overcoming of this polarization, or counter-electro-motive force.

A storage-battery consists of two plates of lead placed in a vessel containing acidulated water. A current of electricity is sent, by means of an ordinary galvanic battery, from one plate of lead to the other. The current decomposes the water, sending the oxygen to one plate and the hydrogen to the other. The oxygen combines with the lead, forming peroxide of lead; and the hydrogen, reaching the other plate, decomposes any salt of lead it may find there, precipitating pure lead, or otherwise escaping in the form of gas. The current is then reversed, and driven through the arrangement in the opposite direction. The current is thus reversed several times, in order to prepare the storage-battery, by making the surfaces of the lead plates porous, and so capable of holding a great quantity of peroxide of lead.

If the lead plates be connected by wire, after the battery has been charged, the oxygen that had been forcibly driven from its combination in the liquid, seeks to recombine, just as a stone forcibly lifted from the earth seeks to return, and the effect of this tendency of the oxygen is to generate an electric current in the opposite direction to the original one. This is the current that has been stored, and is to be utilized as storage.

Gaston Planté made the first storage-battery in 1859. It consisted of two sheets of lead, about three and one quarter feet square, rolled in a cylinder, and placed in a jar filled with dilute sulphuric acid. Strips of felt were placed between the lead sheets. He prepared his battery for use, by sending the current from three Grove cells through it several times in opposite directions. He then charged it, and permitted it to so stand for a short time; he finally discharged it, and it was ready for use.

When the storage-battery is charged, and its poles connected, it works like any other battery. The metallic lead, combining with the acid, forms sulphate of lead; the liberated hydrogen takes the oxygen from the peroxide of lead on the other plate, forming water. When both the lead plates are reduced to the same condition, the battery is discharged.

Faure's secondary battery, or accumulator, differs from Planté's only in the preparation. Faure saves both time and energy by his method. He coats the lead plates with a mixture of minium, or red-lead, and sulphuric acid. This red-lead is largely changed into sulphate of lead, through the action of the acid. The galvanic current, on its first action, changes the sulphate of lead upon one plate into spongy metallic lead, and upon the other plate oxidizes it, forming the peroxide of lead.

A single cell of either Faure or Planté weighs ninety pounds. The box containing these batteries is coated with plumber's cement, to withstand the action of the acid. The thicker the lead plates, the greater will be the storing capacity of the batteries. A secondary battery should be kept in a cool place, as heat diminishes its force.

In the Brush storage system, lead oxide is used in connection with lead plates. The manner of electric treatment is known only to Mr. Brush. He claims a great deal for his system.

Planté has lately much improved his battery, by a new preparatory treatment.

D'Arsonval's secondary battery has a plate of zinc and one of carbon placed in a porous cell filled with small shot, the whole impregnated with a solution of sulphate of zinc.

Varley, Kabath, Houston, and Thomson have given their names to storage-batteries. The latest improvements in secondary batteries are by Tribe, De Lalande, and Chaperon.

In electric railroading a good system of storage would be invaluable, as it would obviate the necessity of using either the rails or auxiliary conductors to convey the fluid from the dynamo to the motor and back. For, besides the great inconvenience of thus conveying the fluid, it occasions, moreover, a great loss of current. But the accumulators thus far devised are too heavy, too expensive, and too prodigal of the primitive current. Only fifty per cent of the invested electricity is returned by an accumulator.

For electric lighting, the accumulator is thus far most valuable. It furnishes an even, constant current. No matter how many or how few lamps may be connected with the battery, they all burn with perfect steadiness and uniform power. Each lamp takes its exact proportion of the power, and no more; so there is no waste.

The motive power of a dynamo furnishing the electricity for illuminating purposes must work with the greatest smoothness. The least failure in steadiness on the part of the driving-engine produces a flicker in the lights, and a stoppage for a second would result in total darkness. The electric current is so sensitive that, when a badly laced band from the driving-wheel of a steam-engine works a dynamo, the lights in a circuit are observed to give a sudden shiver every time the laced ends of the band pass over the drum. The storage-battery, on the contrary, on all occasions furnishes an even flow of current, and so a steady, uninterrupted light.

CHAPTER XVII.

THE TELEPHONE.

The telephone (from the Greek *tele*, far, and *phone*, voice) is a wonderful instrument of recent invention, devoted to the electric transmission of speech. The sensation of sound is produced by the undulatory or vibratory motions of the air impinging on the tympanum or drum of the ear, and thence, by means of a delicate chain of bones and the fluid of the labyrinth, communicated to the auditory nerve.

The undulations of any elastic body, as well as of the air, will produce sound. In fact, solids convey sound better than either liquids or gases, and liquids better than gases. The nature of the sound depends upon the class of waves occasioning it. The lowest tone audible to the human ear is produced by sixteen vibrations in a second, and the highest by about sixteen thousand.

The ear recognizes three varieties in sound—

tone, intensity, and quality. The tone depends on the rapidity of the vibrations; the intensity on the amplitude or depth of the wave; and the quality, according to Müller, is due to the order in which the velocities and changes of density succeed each other in the sound-waves which produce the tone.

If, by any means whatever, we can reproduce the precise vibrations of a sound, they will make the very same impression on the ear as the original sound.

The first attempt at transmitting speech through the agency of electricity was made by Philipp Reis, a Professor of Natural Philosophy in Friedrichsdorf, in 1861. His instrument was a crude one, but the principle was correct. Reis was very poor, very modest, without influential friends, and of a delicate constitution, and consequently his invention fell through for the time being. Reis's first receiver consisted of a helix inclosing an iron rod, and fixed upon a hollow sounding-box. Iron rods, when magnetized by the closing of an electric current, are slightly increased in length; and, when demagnetized by the breaking of the current, are restored to their first length. These differences of length in the rod succeed one another in exact accordance with the closing or breaking of the current occasioned by the vibrations of the sound at the sending-station, and are communicated by the rod to the sounding-box, and thereby rendered audible at the receiving-station. The electro-magnet used by Reis was a knitting-needle wound with silk-covered copper wire, and his sounding-box was a cigar-box.

In 1876 the problem of transmitting speech electrically was practically solved, and the honor of solution is equally claimed by Elisha Gray and Graham Bell. It is on record that both took out patents on the same day, the 14th of February, 1876. When the time of Gray's caveat expired, he was so engrossed with his harmonic telegraph, that he committed the formal error of not having it renewed, and so the American courts have pronounced in favor of Bell's priority.

In the Bell telephone no battery is employed, induced currents doing the work. The action of a magnet on a closed circuit has been already described, under the head of magneto-electricity. When the pole of a magnet is approached to such a circuit, an instantaneous current is induced in the wire. When the pole is withdrawn, another momentary current is induced in a direction opposite to the former current. The first current is called the inverse, because it is opposite to the magnetic current itself; and the last current direct, because it is in a similar direction to the magnetic current. If a galvanometer be placed in a circuit, the conduct of the currents will be made manifest. If, instead of a single approach and withdrawal, the magnet be jerked backward and forward repeatedly, corresponding currents will be induced in the circuit, as will be seen by the motions of the galvanometer-needle. If, instead of a single circuit, we use a coil or helix, the action will be stronger and more manifest. If a core of soft iron be inserted in the helix, it will cause a simultaneous action in the whole coil, and so increase the strength of the induced currents. If we substitute a permanent magnet for the soft-iron core, a similar effect may be produced in the helix, by approaching or withdrawing a soft-iron armature to or from the poles of the magnet. The soft-iron armature will become magnetized or demagnetized, according to its approach to or withdrawal from the permanent magnet, and will react on the wire, producing induced currents in the helix, whose directions are governed by Ampère's formula. Every movement of this armature will cause a proportionate current in the helix. So sensitive is this coil, that it responds to the faintest stir of the armature.

If this armature is replaced by a delicate iron disk, which, under the influence of sound, will vibrate in a manner similar to the tympanum or drum of the ear, the alternate movements of the disk will be transformed into the induced currents, and these will be stronger or weaker, more or less definite, according to the range and complexity of the vibrations. These divers currents flow along the wire to the receiving-station, where they react on another similar iron disk through means of an electro-magnet, reproducing a facsimile of the original vibrations. It is not necessary that the magnetic core, however, should be of soft iron, since the vibratory effects may follow from differential as well as from direct magnetization; and so in the receiver, as in the transmitter, a permanent magnet may be used. Thus electricity affords the means of calling into life, at any given distance, vibrations similar to the vibrations that have been produced, and in this way to give out again in one place tones that have been produced in another place.

It will be understood that the waves or undulations themselves of sound are not carried along the wire; the electric fluid alone traverses the circuit from one station to another. The vibrations are not carried, but reproduced; for it has really been objected that this awful speed of sound overthrows the undulatory theory. Sound travels in the air at the rate of eleven hundred and twenty-five feet per second, in water four and one half times, in silver nine times, in cast-iron ten times, and in hammered iron, where it attains its greatest velocity, seventeen times more rapidly. But this new advance on the old records upsets entirely, it is said, the deductions of Helmholtz. But, indeed, the speed of sound is neither increased nor changed, the sound is simply reproduced.

The Bell telephone consists of a circular wooden box at the extremity of a wooden handle. A magnetic bar runs through the handle, with one of its poles reaching to about the center of the box. This pole of the magnet is surrounded with a helix of very fine copper wire. A screw is fitted to the other pole of the bar, by which it can be moved backward or forward, for the regulation of the instrument. The ends of the helix run down through the handle to its opposite end, and are thence connected with the line-wires.

One of these wires is borne over insulators to the distant station, and the other is run into the ground, as in the ordinary telegraphic circuit. The vibrating plate is a very thin disk of iron, placed immediately in front of that pole of the magnet projecting into the box. The rim of the disk is fastened to the wooden box by means of an India-rubber ring. The disk should be as near as possible to the magnetic pole, without ever actually touching it, while vibrating under the sound of the voice. The mouth-piece is funnel-shaped, the small end of the funnel very close to the vibrating disk, but leaving a small space between the edge of the hole of the funnel and the disk. The wooden box should be so constituted as to act the part of a sounding-box. There are two of these telephones at each station, one to talk into, and which is usually fixed, and the other to hold to the ear.

A system of alarm-bells is attached to the telephone, in order to give notice when an exchange of correspondence is desired. An electric bell is attached to the main circuit, through the medium of a commutator. A wire from the bell, and one from the telephone, are joined to this commutator, which is in connection with the main circuit. This commutator is made to act automatically. A forked hook is attached to a spring moving up and down between the two contacts of the commutator. When the telephone-handle is fastened to the hook, its weight carries down the spring, and connects the main circuit with the bell. When the telephone is removed from its support, the spring, being relieved of its weight, flies up to the higher contact, and connects the telephone with the main circuit. Commutators are also placed in the bell-wires, to make connection, when desired, with the main current, by either pushing an electric button or turning a winch, according to the apparatus.

The battery telephone of Mr. Edison is much more powerful than Mr. Bell's, transmitting sound to a greater distance and with more distinctness. Edison employs a battery in his system, and his apparatus is much more complicated than Mr. Bell's. In battery telephones, secondary coils and induction-currents are used for the main circuit.

Modifications and improvements unnumbered have been introduced into the structure of the telephone in the last few years. When many stations are joined together, as in a city, any two are put in communication by means of a switch-board located at a central station.

An excellent form of battery telephone has been lately devised by George M. Hopkins, of Brooklyn, New York. The disk or diaphragm is made of mica, and is one and three quarters of an inch in diameter. The surfaces between which the diaphragm is clamped are of vulcanite, a material not liable to warp. It is said that this instrument acts as well on the Postal Telegraph Company's wire between New York and Cleveland, a distance of six hundred and fifty miles, as the ordinary telephone does over a distance of three miles. Telephonic communication was successfully carried on through this same instrument, over the same company's line between New York and Chicago, a distance of one thousand miles.

The Postal Telegraph Company has the very best conducting wire yet devised. It is a compound wire, having a core of steel with a copper covering. The steel gives tensile strength and elasticity, and the copper conductivity. This wire is computed to have six times the conducting capacity of an iron wire of equal weight. This wire between New York and Chicago has a resistance of fifteen hundred ohms, the best iron wire over the same route has a resistance of ten thousand ohms, and the average iron wire in common use offers a resistance of fifteen thousand ohms.

Myron L. Baxter, of the United States War Department, is the latest claimant for telephonic honors. He has discovered that, by throwing the whole battery current into the circuit wire, and connecting the diaphragm by a wire with the ground, the vibrations of the diaphragm caused by the voice can be utilized to make or break the current. The effects produced by this system are said to be wonderful indeed. Over a copper-covered wire running alongside the Erie Railroad, speech was distinctly audible between parties seven hundred and twenty-four miles apart.

Well, indeed, has Sir William Thomson called the telephone "the wonder of wonders," even in the wonder-land of electricity!

CHAPTER XVIII.

THE AURORA BOREALIS, OR RED LIGHTS OF THE NORTH.

The aurora borealis is a luminous phenomenon that lights up at night the northern heavens. In the neighborhood of the Arctic Circle it is almost a permanent visitor, but north or south of this circle its appearance is less frequent. To the inhabitants of temperate latitudes it is rarely visible, and never in all its matchless beauty. Indeed, the beauty of this splendid meteor is beyond the reach of language, and must be seen in its Arctic glory to be adequately prized.

In winter, when the sun travels south along the ecliptic, the Arctic regions are deprived more and more of his beams, until at last he hides himself completely from view for weeks together. In such times the northern light is, indeed, a welcome visitant to the dwellers on the shores of the Polar Sea. The auroral light is sufficient to allow them to go about the ordinary purposes of life. This light is brighter than the moon's in its first quarter, but scarcely ever reaches the luster of the full moon, though it is said by travelers to have enabled them to read ordinary print.

The aurora sometimes presents the appearance of a bank of dingy clouds, having the form of a circular segment resting its ends on the eastern and western horizon. The upper portion of this segment is illumined by a bluish-white band of light, averaging 3° in depth. The matter composing the cloud-bank is so extremely tenuous that very faint stars are visible through it, their light passing through undimmed. This cloud begins to assume shape soon after the sun's setting, and, as the twilight fades, it gradually lights up, sometimes throwing out streamers at regular intervals, presenting the precise appearance of a comb. The segment is a portion of a circle whose center is the earth's magnetic pole. This pole is at present located in the Island of Boothia Felix.

Again, the aurora borealis sometimes appears in the pillar-form. Large pillars of light seem built up against the northern sky, leaning in a direction parallel to the dipping-needle. These pillars or streamers are in perpetual motion, and look as if they were painted on a flag or curtain incessantly swayed by the wind.

The auroral light varies very much as regards color. It being chiefly an electric phenomenon, the color is determined by the rarity or density of the atmospheric region through which the current passes. It is well established that the most rarefied air produces a white light; the most dry air red; and the most damp produces yellow streaks. "In the higher latitudes," says Humboldt, "the prevailing color of the polar light is usually white, while it presents a milky hue when the aurora is of faint intensity. When the colors brighten, they assume a yellow tinge; the middle of the broad ray becomes golden yellow, while both the edges are marked by separate bands of red and green. When the radiation extends in narrow bands, the red is seen above the green. When the aurora moves sidewise from left to right, or from right to left, the red appears invariably in the direction toward which the ray is advancing, and the green remains behind."

The aurora is not at all local in its character, as it has been witnessed simultaneously in Europe, Asia, and America. Like the rainbow, it appears differently to different observers. While to all it preserves its characteristic features, still each one sees his own aurora, as he does his own rainbow. It is owing to this peculiarity that there has been such a vast discrepancy in the estimate of its height. In trying to find the aurora's parallax, no two observers can see the same point, at the same time, in the same way. In all probability, its average height may be set down at seventy miles above the earth's surface. Some auroras are much higher, some much lower. There is a popular belief that a crackling noise accompanies the aurora, resembling the swaying of silk in the wind; but the celebrated travelers and voyagers, Parry, Franklin, Richardson, Gieseke, Bravais, Wrangel, and Anjou, never heard it; so that it must, in all probability, be attributed to the cracking of distant ice-fields.

It is quite safe to say that the aurora borealis is of electric origin, and is very intimately connected with the magnetism of the earth. It very sensibly affects the magnetic needle, causing it to tremble and deviate from point to point. Its unusual splendor presages electric storms, and its frequency and grandeur are indexes of solar paroxysms.

Sun-spots are great chasms in the sun's shells, rent and torn by solar explosions. These chasms are enormous in size, one of them, for instance—but, indeed, the greatest known to astronomy—measured 153,500 miles in diameter, and would easily hold one hundred globes the dimensions of the earth. An increase in the number of spots shows unwonted activity in the great central orb. These spots have a periodicity. They reach their greatest number every eleven years. The auroral displays, as regards brilliancy and frequency, follow the same period. In fact, the solar spots influence the aurora borealis. We have had a very striking and signal proof of this quite recently. On April 16, 1882, two immense spots appeared upon the sun, and presented the unusual spectacle of undergoing perceptible change right under the eye of the observer. Commotions of an unwonted character were going on in the sun. The magnetism of the earth almost immediately responded to the magnetic storm in the sun. An aurora of great splendor made its appearance that night. A magnetic storm raged on the earth the next day. Messages were sent along the wires without the use of batteries; in some places the wires refused to work, and the Atlantic cable was crippled.

From the 12th to the 19th of November, 1882, a tremendous spot, exceeding in magnitude the April spots, traveled across the sun's disk. During a portion of this period, a very hurricane of magnetic forces raged on the earth, culminating, on the 17th, in one of the most terrific magnetic storms ever recorded. During all this time fine auroras were observed in Europe, but the chief displays in this country were on the nights of the 17th and 19th. The telegraph wires were again worked without batteries. Sparks of fire leaped from wires and instruments. The operators were appalled, switch-boards were burned, and keys melted. The electric disturbance was without a parallel. The auroral displays were wonderfully brilliant. An immense band of fire spanned the northern heavens, and a blending of rose-color, green, violet, yellow, and orange lights added beauty and variety to the scene.

The last mighty spot was in the beginning of last October, just after the passage of the comet, when beautiful auroras appeared in England, Scotland, and Western Europe.

The years 1881 and 1882, and beginning of 1883, corresponded to the maximum of the sun-spot period, and, sure enough, they have been remarkable for auroras and magnetic disturbances on our planet's surface.

Lenström has lately given us a direct and definite proof of the electrical nature of the aurora borealis. In November and December, 1882, he produced artificial auroras at Sodankylä and Kultala, Lapland. The first experiment was made on the mountain of Oratunturi, near the village of Sodankylä; and the second, on the mountain of Pietarintunturi, near Kultala. Both experiments were, in the main, identical. A long copper wire was bent into a series of squares within squares, and placed, in an upright position, on the top of the mountain. The bent wire presented a total space of over nine hundred square yards. At distances of more than one half a yard, along the whole wire, on opposite sides, were projected points of tin. The copper wire was connected with a galvanometer, and thence with the earth. The experiments were entirely successful. Artificial auroras were called into life, and the fact mainly established that the aurora borealis is an electric light.

Those who have gone down in ships to the southern seas tell of similar auroras streaking the heavens toward the south magnetic pole. The northern and southern lights are now classed together, and called very properly the polar lights.

APPENDIX.

EXPERIMENTAL INVESTIGATION OF TABLE-MOVING.*—
BY MICHAEL FARADAY.

THE object which I had in view in this inquiry was not to satisfy myself—for my conclusion had been formed already on the evidence of those who had turned tables—but that I might be enabled to give a strong opinion, founded on facts, to the many who applied to me for it. Yet the proof which I sought for, and the method followed in the inquiry, were precisely of the same nature as those which I should adopt in any other physical investigation. The parties with whom I have worked were very honorable, very clear in their intentions, successful table-movers, very desirous of succeeding in establishing the existence of a peculiar power, thoroughly candid, and very effectual. It is with me a clear point that the table moves when the parties, though they strongly wish it, do not intend, and do not believe that they move it by ordinary mechanical power. They say the table draws their hands; that it moves first, and they have to follow it, that sometimes it even moves from under their hands. With some the table will move to the right or left according as they wish or will it, with others the direction of the first motion is uncertain; but all agree that the table moves the hands, and not the hands the table. Though I believe the parties do not intend to move the table, but obtain the result by a *quasi*-involuntary action, still I had no doubt of the influence of expectation upon their minds, and through that upon the success or failure of their efforts.

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* From the London "Athenæum," July 2, 1853.

The first point, therefore, was to remove all objections due to expectation, having relation to the substances which I might desire to use: so, plates of the most different bodies, electrically speaking, namely, sand-paper, mill-board, glue, glass, moist clay, tin-foil, card-board, gutta-percha, vulcanized rubber, wood, etc., were made into a bundle and placed on a table under the hands of a turner. The table turned. Other bundles of other plates were submitted to different persons at other times, and the tables turned. Henceforth, therefore, these substances may be used in the construction of apparatus. Neither during their use nor at other times could the slightest trace of electrical or magnetic effects be obtained.

At the same trials it was readily ascertained that one person could produce the effect; and that the motion was not necessarily circular, but might be in a straight line. No form of experiment or mode of observation that I could devise gave me the slightest indication of any peculiar natural force. No attractions, or repulsions, or signs of tangential power appeared, nor anything which could be referred to other than the mere mechanical pressure exerted inadvertently by the turner. I therefore proceeded to analyze this pressure, or that part of it exerted in a horizontal direction—doing so, in the first instance, unawares to the party. A soft cement, consisting of wax and turpentine, or wax and pomatum, was prepared. Four or five pieces of smooth, slippery card-board were attached one over the other by little pellets of the cement, and the lower of these to a piece of sand-paper resting on the table; the edges of these sheets overlapped slightly, and on the under surface a pencil-line was drawn over the laps so as to indicate position. The upper card-board was larger than the rest, so as to cover the whole from sight. Then the table-turner placed the hands upon the upper card, and we waited for the result. Now, the cement was strong enough to offer considerable resistance to mechanical motion, and also to retain the cards in any new position which they might acquire, and yet weak enough to give way slowly to a continued force. When at last the tables, cards, and hands all moved to the left together, and so a true result was obtained, I took up the pack. On examination, it was easy to see, by the displacement of the parts of the line, that the hand had moved farther than the table, and that the latter had lagged behind; that the hand, in fact, had pushed the upper card to the left, and that the under cards and the table had followed and been dragged by it. In other similar cases when the table had not moved, still the upper card was found to have moved, showing that the hand had carried it in the expected direction. It was evident, therefore, that the table had not drawn the hand and person round, nor had it moved simultaneously with the hand. The hand had left all things under it behind, and the table evidently tended continually to keep the hand back.

The next step was to arrange an index, which should show whether the table moved first, or the hand moved before the table, or both moved or remained at rest together. At first this was done by placing an upright pin fixed on a leaden foot upon the table, and using that as the fulcrum of a light lever. The latter was made of a slip of foolscap paper, and the short-arm, about one quarter of an inch in length, was attached to a pin proceeding from the edge of a slipping card placed on the table, and prepared to receive the hands of the table-turner. The other arm, of eleven and one half inches long, served for the index of motion. A coin laid on the table marked the normal position of the card and index. At first the slipping card was attached to the table by the soft cement, and the index was either screened from the turner, or the latter looked away; then, before the table moved, the index showed that the hand was giving a resultant pressure in the expected direction. The effect was never carried far enough to move the table, for the motion of the index corrected the judgment of the experimenter, who became aware that, inadvertently, a side force had been exerted. The card was now set free from the table, i. e., the cement was removed. This, of course, could not interfere with any of the results expected by the table-turner, for both the bundle of plates spoken of and single cards had been freely moved on the tables before; but now that the index was there, witnessing to the eye, and through it to the mind, of the table-turner, not the slightest tendency to motion either of the card or of the table occurred. Indeed, whether the card was left free or attached to the table, all motion or tendency to motion was gone. In one particular case there was relative motion between the table and the hands: I believe that the hands moved in one direction; the table-turner was persuaded that the table moved from under the hand in the other direction; a gauge, standing upon the floor, and pointing to the table, was therefore set up on that and some future occasions, and then neither motion of the hand nor of the table occurred.

A more perfect lever apparatus was then constructed in the following manner: Two thin boards, nine and a half inches by seven inches, were provided; a board, nine by five inches, was glued to the middle of the under side of one of these (to be called the table-board), so as to raise the edges free from the table; being placed on the table, near and parallel to its side, an upright pin was fixed close to the farther edge of the board, at the middle, to serve as the fulcrum for the indicating lever. Then four glass rods, seven inches long and one fourth of an inch in diameter, were placed as rollers on different parts of this table-board, and the upper board placed on them; the rods permitted any required amount of pressure on the boards, with a free motion of the upper on the lower to the right and left. At the part corresponding to the pin in the lower board, a piece was cut out of the upper board, and a pin attached there which, being bent downward, entered the hole in the end of the short arm of the index-lever; this part of the lever was of card-board; the indicating prolongation was a straight hay-stalk fifteen inches long. In order to restrain the motion of the upper board on the lower, two vulcanized rubber rings were passed round both, at the parts not resting on the table; these, while they tied the boards together, acted also as springs; and while they allowed the first feeblest tendency to motion to be seen by the index, exerted, before the upper board had moved a quarter of an inch, sufficient power in pulling the upper board back from either side to resist a strong lateral action of the hand. All being thus arranged, except that the lever was away, the two boards were tied together with string, running parallel to the vulcanized rubber springs, so as to be immovable in relation to each other. They were then placed on the table, and a table-turner sat down to them; the table very shortly moved in due order, showing that the apparatus offered no impediment to the action. A like apparatus, with metal rollers, produced the same result under the hands of another person. The index was now put into its place and the string loosened, so that the springs should come into play. It was soon seen, with the party that could will the motion in either direction (from whom the index was purposely hidden), that the hands were gradually creeping up in the direction before agreed upon, though the party certainly thought they were pressing downward only. When shown that it was so, they were truly surprised; but when they lifted up their hands and immediately saw the index return to its normal position, they were convinced. When they looked at the index and could see for themselves whether they were pressing truly downward or obliquely, so as to produce a resultant in the right- or lefthanded direction, then such an effect never took place. Several tried for a long while together, and with the best will in the world; but no motion, right or left, of the table, or hand, or anything else, occurred.

I think the apparatus I have described may be useful to many who really wish to know the truth of nature, and would prefer that truth to a mistaken conclusion; desired, perhaps, only because it seems to be new or strange. Persons do not know how difficult it is to press directly downward or in any given direction against a fixed obstacle; or even to know only whether they are doing so or not, unless they have some indicator which, by visible motion or otherwise, shall instruct them; and this is more especially the case when the muscles of the fingers and hand have been cramped and rendered either tingling, or insensible, or cold, by long-continued pressure. If a finger be pressed constantly into the corner of a window-frame for ten minutes or more, and then, continuing the pressure, the mind be directed to judge whether the force, at a given moment, is all horizontal, or all downward, or how much is in one direction and how much in the other, it will find great difficulty in deciding, and will at last become altogether uncertain—at least, such is my case. I know that a similar result occurs with others; for I have had two boards arranged, separated, not by rollers but by plugs of vulcanized rubber, and with the vertical index;

when a person, with his hands on the upper board, is requested to press only downward, and the index is hidden from his sight, it moves to the right, to the left, to him, and from him, and in all horizontal directions; so utterly unable is he strictly to fulfill his intention without a visible and correcting indicator.

Now, such is the use of the instrument with the horizontal index and rollers: the mind is instructed, and the involuntary or *quasi*-involuntary motion is checked in the commencement, and therefore never rises up to the degree needful to move the table, or even permanently the index itself. No one can suppose that looking at the index can in any way interfere with the transfer of electricity or any other power from the hand to the board under it, or to the table. If the board tends to move, it may do so, the index does not confine it; and if the table tends to move, there is no reason why it should not. If both were influenced by any power to move together, they may do so—as they did, indeed, when the apparatus was tied, and the mind and muscles left unwatched and unchecked.

M. FARADAY.

ROYAL INSTITUTION, *June 27, 1853.*

THE END.

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